Seventh Annual Field Conference

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS

WATERTON

September 1957

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GUIDE BOOK

Seventh Annual
Field Conference

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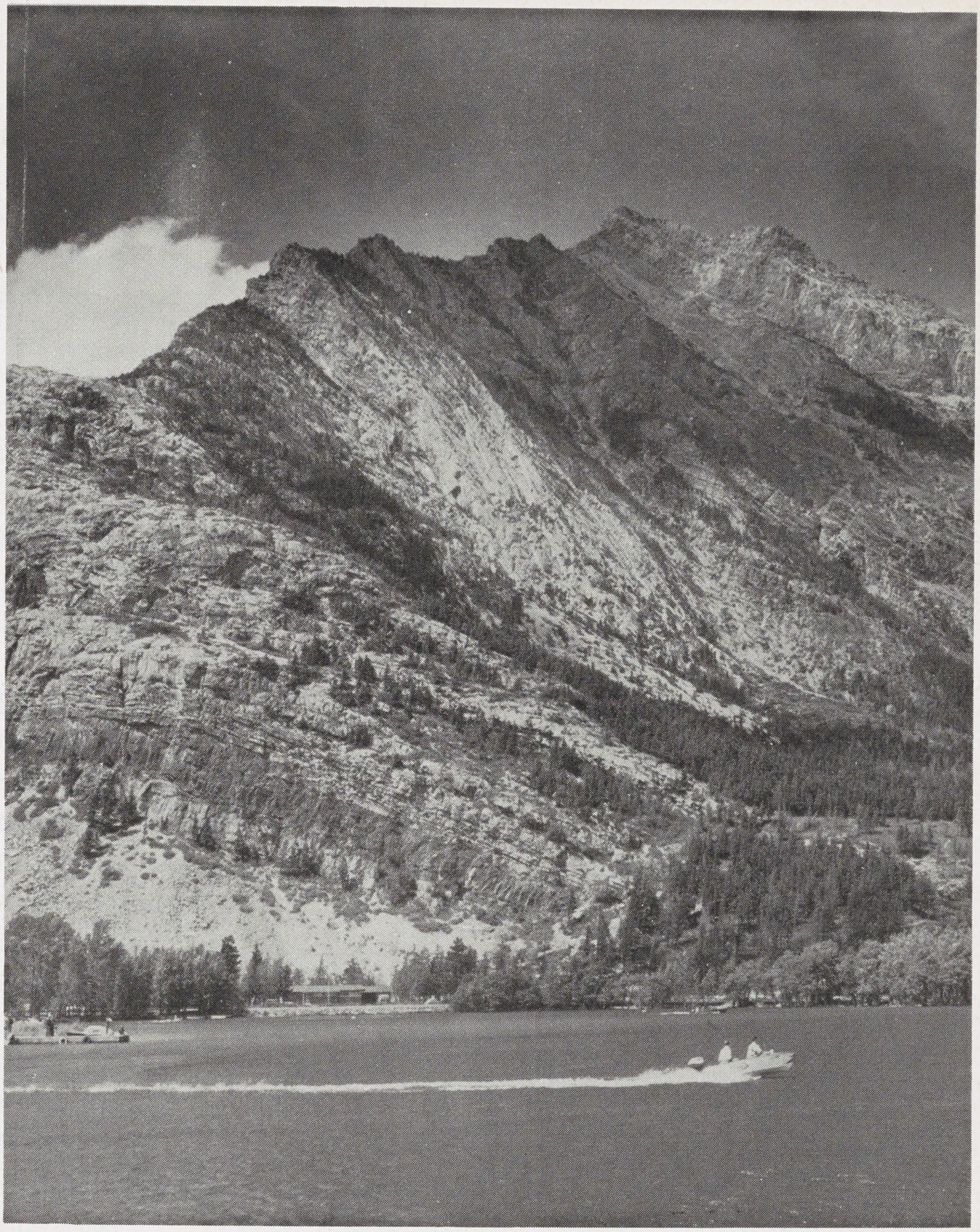

FRONTISPIECE

Mount Crandell, Waterton. Precambrian, Altyn and Appekunny dolomites.

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CONTENTS

ILLUSTRATIONS

PREFACE

The Seventh Annual Field Conference might also be properly called the First International Field Conference of the Alberta Society of Petroleum Geologists. Although previous conferences have been international in attendance, this is the first time we have crossed the forty-ninth parallel.

In keeping with this "first" the editorial committee believes the papers which follow represent the latest, stimulating (and controversial) geologic thought. We consider ourselves very fortunate in this respect, too, as it has been only four years since a most complete symposium (1953) of southern Alberta geology was published. The editors of that publication, in their foreword, state that the area is ". . . as yet imperfectly known. Present known facts are numerous. Those that remain to be learned are infinite in number". We hope that the facts, deductions, theories and conclusions contained in this volume will advance our understanding not only of southern Alberta, but of Geology.

THE EDITORS

(1953) – Third Annual Field Conference and Symposium – Alberta Society of Petroleum Geologists.

THE SWING BACK TO SOUTHERN ALBERTA

THEO. A. LINK

INTRODUCTION:

Prior to the Leduc discovery in 1947, more holes per square mile had been drilled in Southern Alberta in search for oil than in the northern and central parts of the Province. This was probably due to the nearness to the oil fields in Northern Montana, as well as the accessibility of the area. The first drilling for oil in Western Canada was done in Waterton Lakes Park in the Rocky Mountains in Southern Alberta, and Medicine Hat is known for its early gas wells which supplied light for that city so plentiful that it was not thought important enough to turn the lights off during the day time. The gas was discovered by drilling before the turn of the Century (1890). The largest gas well in the British Empire was drilled in Southern Alberta at Dead Horse Coulee in 1923 with a flow of more than 60 million cubic feet per day. The small, but now abandoned Red Coulee oil field, was discovered in the year 1922, and such results also contributed much to the reason why oil and gas hunting was concentrated in Southern Alberta. Of course Turner Valley, in the more northerly portion of Southern Alberta, was also a great factor in keeping the search toward the south portion of the province.

During the years previous to the Leduc discovery, the exploration efforts swung from the foothills to the plains several times, and in the city of Lethbridge many geological and geophysical parties had headquarters during the summer months. Immediately after the Leduc discovery, most of the exploratory effort was concentrated in the central and northern part of the Province, but a swing back to Southern Alberta is in evidence, and that more and larger discoveries will be made is almost certain, for the simple reason that the early drilling was not carried deep enough to test all possible oil and gas formations above the Precambrian, and because the shallower horizons were not properly tested by modern methods. The Post-Leduc Pincher Creek gas discovery in the Foothills, and the more recent Shell oil discovery in that same area, as well as the Savanna Creek find in the Rocky Mountains, all indicate that Southern Alberta is now poised for more thorough searching and modern testing. Other finds of lesser importance in the Plains area have been made recently in the southern part of the province, and no doubt more are to follow. A field conference in this area is therefore quite appropriate at this time, and the City of Lethbridge is a logical place from which to stage such a conference. Citizens of this progressive city have in the past contributed much in money and effort to find oil and gas in Alberta, and I personally would like to see something big unearthed near this centre of aggressive and friendly people in Southern Alberta.

Scores of Canadian geologists have won their spurs as field geologists here in Southern Alberta, and several of these have gone a long way in the petroleum industry since their early days as assistants on the Geological Survey of Canada and with oil companies. I had, at one time, the first graduate in geology from the University of Alberta as my plane-table man, but I must admit that I had trouble convincing him that the plane-table and alidade were more suitable and adaptable for structure-contour mapping than is the transit.

PHYSIOGRAPHIC SUB-DIVISIONS OF SOUTHERN ALBERTA

The physiographic sub-divisions of Southern Alberta are comparatively well defined because of their being almost entriely due to easily recognized structural conditions. They are as follows:

(1) Past President, A.A.P.G.
President, Cree Oil of Canada Ltd., Calgary.

(a) The Rocky Mountain Terrain.
(b) The Foothills Belt.
(c) The Plains Area in which the following broad structural features are recognized at the surface:

(i) The Alberta Syncline,
(ii) The Sweetgrass Arch,
(iii) The north extension of the Sweetgrass Hills intrusives,
(iv) The Cypress Hills.

In the Plains Area, where part of this field conference is being held, there are more surface outcrops per square mile than in any other part of the Province of Alberta and consequently considerable structure-contour mapping of surface outcrops is feasible and practical in most of this area, in spite of the several recessional and/or terminal morainic deposits scattered throughout the area. A contribution by Mr. G. C. Wells will dwell upon the age of the Sweetgrass Arch.

Some Interesting Geological Features of Southern Alberta

In Southern Alberta, the geologist may study the entire stratigraphic column from the Precambrian through the Palaeozoic, the Mesozoic and the Tertiary sediments, and on top of that some very interesting glacial geological features. Excellent sections of the Precambrian sedimentaries are exposed in the Waterton Lakes area, while further north in the Crowsnest area, the Paleozoics and the Mesozoic are well exposed and here the type-sections of the Jurassic Fernie may be studied.

Our tireless investigator, Bill Gussow, will give us the benefit of his studies of the Cambrian and Precambrian differentiation dispute or problem, and the outcrops of the Precambrian in the Waterton Lakes area should be of benefit to all of us with respect to this subject. Of course, the scenery alone in that area will be worthy of the trip.

Any discusion or presentation of Rocky Mountain and/*or* Foothills structure is always a popular subject at any gathering of Western Canada geologists. Unfortunately, the number of theories believed in is usually arrived at by taking the number of individual authors presenting such theories and multiplying that factor by the number of geologists listening to such presentations, and then adding to that result the number of miles the Lewis Overthrust Sheet was supposed to have travelled before movement along its plane ceased. Of course, there are other ways in arriving at that or other conclusions. The field trip into the mountains should answer many of the un-solved problems.

A contribution by Dr. R. E. Follinsbee on the age of the Crowsnest Volcanics should also be of great interest to those working in the Foothills area of Southern Alberta.

In the Sweetgrass Hills area, on and near the International Boundary line, one may study the section from the Milk River Sandstone of Upper Cretaceous age down into isolated outcrops of the Jurassic Ellis and Palaeozoic Madison limestone. Igneous dykes are common in this area. Excellent sections of the Bearspaw Shale are exposed around Lethbridge and upstream from that city along the Oldman and St. Mary's Rivers. In the Manyberries area the Bearspaw shale is again well exposed, and in it are some very spectacular sandstone dykes cutting the shale just like igneous dykes. Large ammonities in the Bearspaw shale are common, such as *Placenticeras meeki.* Bentonite or volcanic ash layers are common in this formation and are a great aid in surface structure-contour and sub-surface mapping. Normal faulting as observed in the coal mines near Lethbridge and in the outcrops along the river banks are evidence of tensional stresses in this area, as are also the sandstone dykes already mentioned.

The Tertiary-Upper Cretaceous contact will be discussed by Mr. D. Bossort in a contribution entitled "The Stratigraphy of the Porcupine Hills", and this should be of great interest to those who wish to drill really deep Devonian test holes in the Alberta Syncline of Southern Alberta.

The excellent sections of the Lower Milk River Sandstone along the river of that name give rise to high-walled narrows or canyons north of the Sweetgrass Hills, and indicate the Post Glacial age of most of that river valley. This sandstone is an important aquafier in Southern Alberta, and the water is, in some localities, quite highly charged with natural gas to such an extent that the farmers separate it from the water and utilize it for heating purposes from wells of relatively shallow depths.

In May of this year,, the area embracing the relatively little known but most interesting "Writing on Stone" by the Indians on the Lower Milk River Sandstone of Southern Alberta was opened as a Provincial Park, and "Heap Big Chief" Bill Gallup will address this gathering on a more detailed account of his translations of the writings into English. (Chief Gallup later in life learned to read and write English in the public schools of Saskatchewan.)

In the Cypress Hills area of eastern Southern Alberta ,one may observe land-slide slumping on a grandiose scale. In fact to one government geologist, the up-turned blocks of Foxhills Sandstone (now called Blood Indian) were so large that deep-seated faulting on a large scale was postulated for that area. The presence of horned toads also adds interest to this area.

The Bad Lands of upper Belly River age in the extreme southeast corner of Southern Alberta rival those of the Drumheller area further north, and they also contain land plants and animal remains in profusion. Dr. L. S. Russell will address this audience on the vertebrate fossils found in this and other areas of Southern Alberta. To be noted is the abundance of vertebrate and land plant fossils in both the Belly River and the Edmonton formations. The latter being, as you all know well developed in the Bad Lands of the Drumheller area of Southern Alberta. Few know that the Bad Lands of the Lost River Area of southeastern Alberta are almost as spectacular as those of the Drumheller Area – with rattle snakes added to make things more interesting.

The Monarch Fault system along the Oldman River west of Lethbridge is something no Alberta geologist should omit from his tour of the country, and a reasonable explanation of these up-turned Foxhills sandstone and oyster beds would be welcome.

The Pleistocene geology of this area will be discussed by Mr. Stalker, and anyone familiar with the area knows that it is replete with numerous types of glacial deposition and erosion, and that many un-solved problems await further and more intensive study. The presence of terminal or recessional moraines on the north side of many of the dry coulees of Southern Alberta suggest that these abandoned stream channels were probably formed laterally to the front of the receding ice sheet, for the simple reason that higher land to the south, caused mostly by the Sweetgrass Hills, prevented the melting ice waters from doing otherwise. The Sweetgrass Hills were not completely covered by the ice sheet, and apparently stood out as "nunataks". North of them, the Milk River valley was formed in part at the front of the receding glacier where it was entrenched higher than the later formed dry coulees and stream channels to the north.

One might ask, of what earthly use is a knowledge of the Tertiary and particularly the Glacial deposits to the finding of oil or gas in Southern Alberta? It is possible that those who are to discuss these two subjects might, on first thought, admit that really there is nothing of interest to the petroleum geologists, but such is not the case. Although, there may be no oil or gas accumulations in the uppermost Tertiary and the Glacial deposits of Southern Alberta,

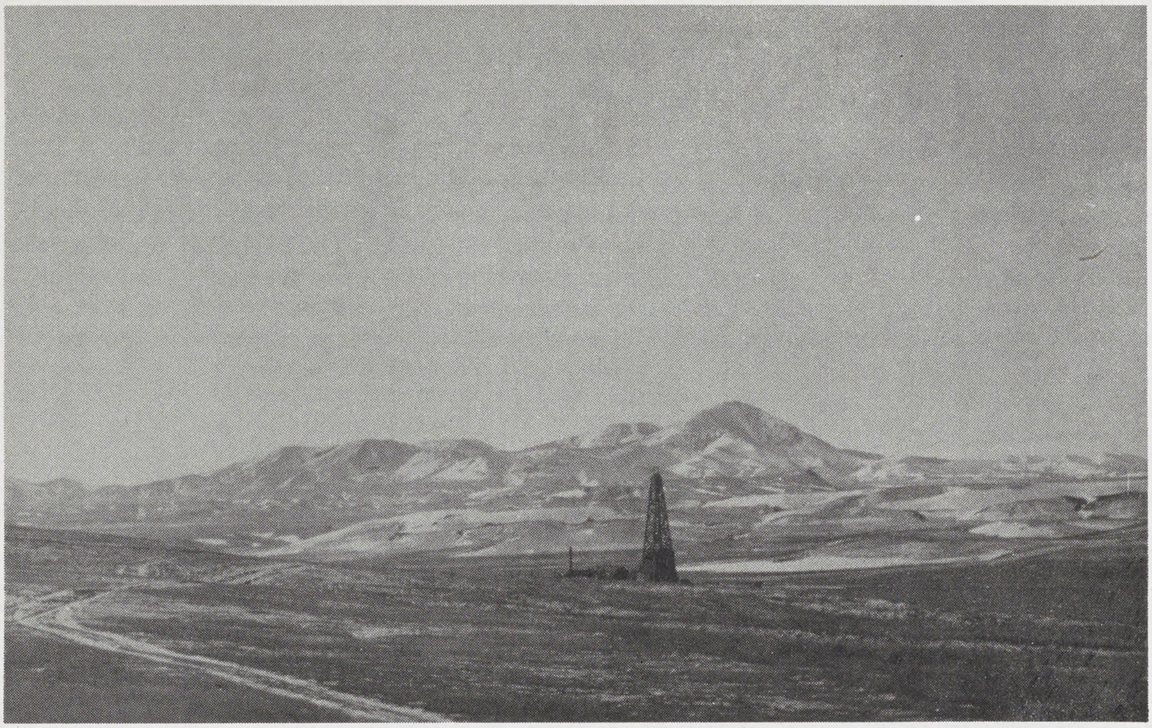

PLATE 1

Wildcat test on American side near International Boundary north of the Sweetgrass Hills igneous up-lift in background. 1927.

PLATE 2

One of the "Buttes" of the Sweetgrass Hills igneous up-lift. This is West Butte (a hay-stack in foreground).

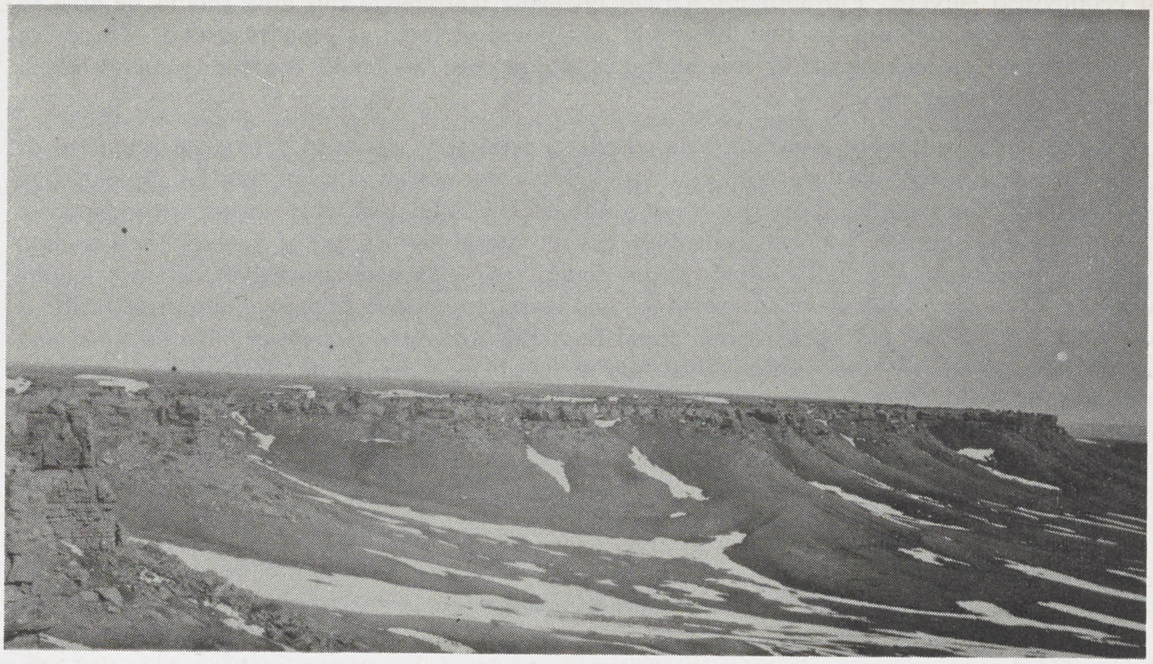

PLATE 3

Lower Milk River (Virgelle) sandstone escarpment near Coutts, Alberta, on American side.

PLATE 4

Rye-Grass sandstone in Bearpaw shale along Oldman River in Rye-Grass Flats, Alberta.

knowledge of the areal extent, thickness and nature of these deposits is of great importance to geophysical surveys. Furthermore, a field geologist working in this area should be able to recognize glacial deposits so that he might not interpret them as something else. These are only a few suggestions regarding this matter, and I'm sure we could enumerate many others if given more thought.

There are many more interesting supposedly solved and un-solved geological problems at the surface and in the sub-surface of Southern Alberta, and some of them will be presented in contributions not mentioned in this short outline. This is an area where many of the pioneers of Canadian geology worked and contributed their interpretations to the best of their ability. Mistakes have been, and will continue to be made, but each new generation of investigators adds more to the accumulated knowledge, and therefore, in spite of the numerous publications available, the last has not been written about Southern Alberta geology, nor have the final and correct interpretations been made. With this in mind, let us carry on, gather more data, re-interpret, and thus strive to attain that which is unattainable — the absolute truth. For that, I am told, and believe has been reserved exclusively for the angels!

CAMBRIAN AND PRECAMBRIAN GEOLOGY OF SOUTHERN ALBERTA

WILLIAM CARRUTHERS GUSSOW [1]

Introduction

In order to give better perspective to geologic time, a new geologic time classification is introduced herewith. The term *Postlipalian* is proposed to designate the fossil record from the base of the Cambrian to the present; *Eozoic* is introduced to represent the youngest era of Precambrian time, and is divided into the *Lipalian* and *Beltian* periods. Available information, both published and new, on the Cambrian and Precambrian of southern Alberta is briefly summarized and reclassified under the new time classification proposed. Because of its importance, attention is drawn to the profound sub-Devonian unconformity .

It has become obvious, both from a tectonic standpoint and from radioactivity age dating, that our Precambrian time classification is in need of revision, but in spite of this knowledge most Precambrian geologists are still using such obsolete terms as Proterozoic, Algonikian, Archaean, *et cetera.* The old concept of a two-fold subdivision of the Precambrian is no longer valid, and as long as this practice continues we will never be able to clear up the many problems of Precambrian geology.

It is interesting to note here, that in 1915 Waldemar Lindgren strongly recommended discarding Algonkian and Archaean, and advocated separating the Belt series from the older Precambrian as the Beltian system.

In order to present a truer perspective of geologic time, a new time classification has been adopted for the Precambrian and is here introduced, in part, for the first time. This will be enlarged on in a more comprehensive paper now in preparation. The tentative revised table of formations for southern Alberta — Table I, is submitted as a step in this direction.

The first positive step in establishing our conventional Geologic Time Classification of the geological record was taken about 120 years ago (A. Sedgwick, 1838, Geological Society of London Proc., Vol. 2, No. 58, pp. 684-685). Since then, it has been subjected to periodic review and revision as our knowledge of the facts increased.

The base of the Cambrian has long been recognized as marking a major division point in geologic time. The younger division comprises the fossil record, whereas the older division, although abundant evidence of primitive life exists — especially in the youngest formations, is handicapped by the complete lack of known diagnostic fauna. This division is so great that even in our profession, geologists are divided into "soft rock" and "hard rock".

The geological record can thus be divided into two major divisions. The older of these has come to be known as the Precambrian and comprises the whole geological record up to and including the Lipalian period†. The younger division representing the complete fossil record, is here designated the Postlipalian†† division. This comprises the classic subdivision of the fossil record into three eras — Palaeozoic, Mesozoic, and Cenozoic — each of which is further sub-

(1) Staff Geologist, Union Oil Company of California, Calgary, Alberta.

† Introduction of the terms "Lipalian" and "Beltian" to represent the two youngest Precambrian periods (or systems) was made in the discussion of a paper by J. E. Reesor of the Geological Survey of Canada, in a symposium on "The Proterozoic in Canada", at the annual meeting of the Royal Society of Canada in Montreal on June 12, 1956. Further mention was made in a paper by the writer entitled "Lipalian Interval Evaluated", presented to the Geological Society of America at the annual meeting in Minneapolis on November 1, and to the Alberta Society of Petroleum Geologists in Calgary on Decemebr 10, 1956. The subject is an integral part of a broader study supported by a grant-in-aid from the Geological Society of America.

†† Postprecambrian was recently introduced (1957) by the Geological Survey of Canada as a reference term for this division. Like afterbeforecambrian, the term is prolix.

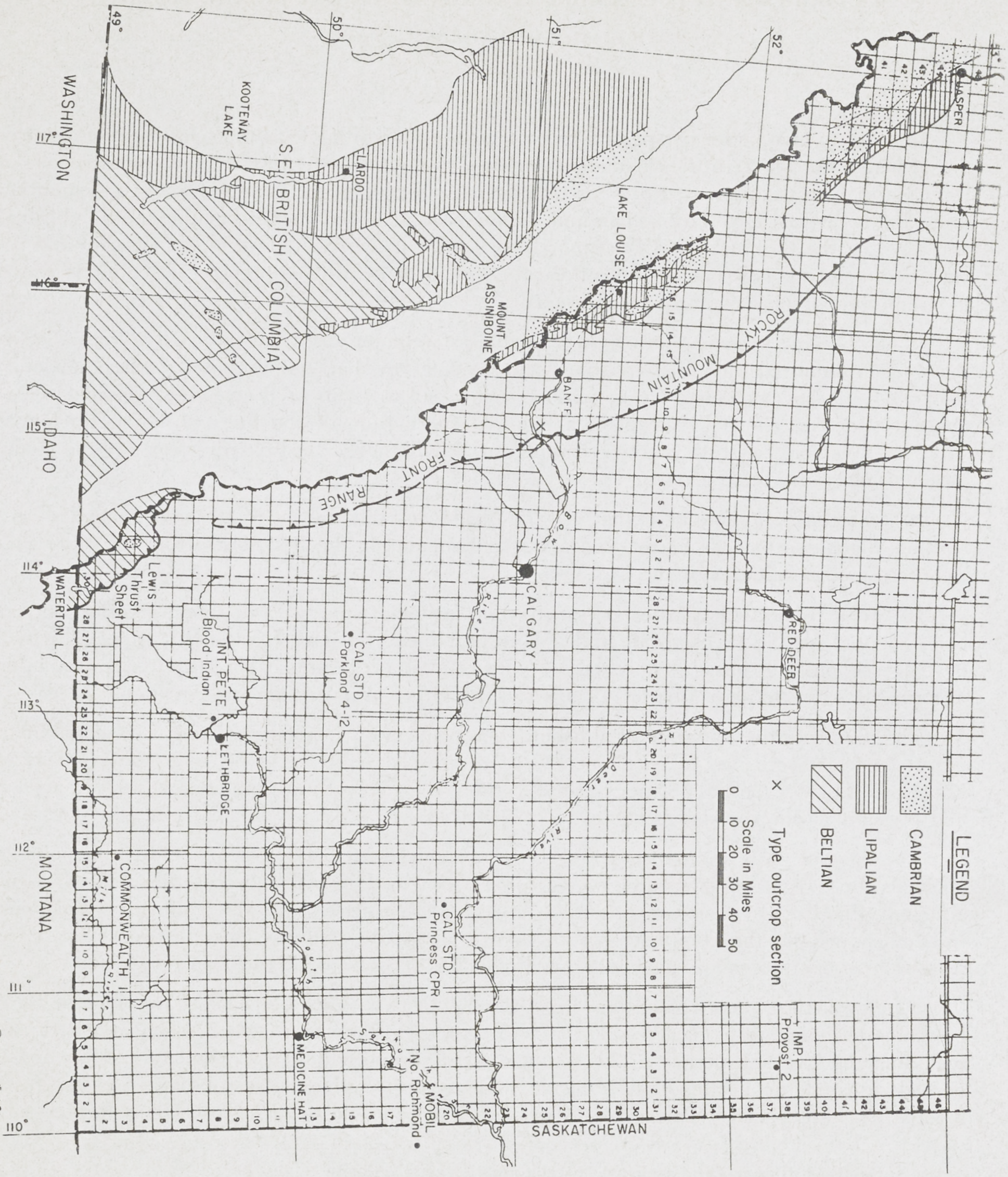

FIGURE 1.

INDEX MAP OF SOUTHERN ALBERTA

Showing location of deep basement tests, and Precambrian outcrop areas.

divided into periods or systems, based on faunal assemblages. As the Precambrian lacks a diagnostic fossil record, it is not possible to subdvide it into eras and periods as has been done for the Postlipalian, and other methods must be resorted to.

Although they are counterparts in the two-fold division of the geologic record, Postlipalian and Precambrian are merely reference terms and are in no way equated measures of geologic time: whereas Postlipalian time is believed to represent some 500 million years in total duration, Precambrian time is at least five or six times as long.

The term Lipalian (lost record) was first introduced at the International Geological Congress in Stockholm (1910) in the classic paper by C. D. Walcott on "The Abrupt Appearance of the Cambrian Fauna on the North American Continent". It was applied to the lost time interval represented by the erosional unconformity between the Belt series and the Lower Cambrian in Montana. Lipalian is here reintroduced to designate the geologic period (or system) immediately preceding the Cambrian period and following the Beltian period.

The Lipalian period of time is represented by the Hector and Corral Creek formations of Banff National Park, and by the Horsethief Creek and Toby formations of southeastern British Columbia (J. F. Walker's original Windermere series). To date, no fauna has been discovered in the strata here assigned to the Lipalian system. Primitive fossils have been described from the Beltian and this is designated as the age of Cryptozoans. The Purcell series and the Belt series are assigned to the Beltian system (as are the Grand Canyon series, the Llano series, *et cetera.* – Walcott,) and the Grenville series in eastern Canada, based on age dating and the presence of Cryptozoans or *Eozoon canadense.*

V. J. Okulitch (1956), recognizing the close time relationship of the Windermere to the Cambrian, elevates it to systemic rank, and includes it at the bottom of the Palaeozoic. Although this excellent suggestion is considered to be in much better perspective, it is not regarded as practical. Although closely related to the Palaeozoic era in time, it is necessary to separate these two new periods of geologic time from both the Palaeozoic above and from the basement rocks of the Interior Plains, and also from the much older crystalline rocks of the Shield. The only practical solution is to introduce a new era term immediately preceding the Palaeozoic era, and to include in it the Lipalian and Beltian periods of time. After careful consideration, Eozoic (dawn of life) has been selected for this new era. This term was first proposed by J. W. Dawson in 1868 (Acadian Geology) for the age of *Eozoon canadense.*

General Geology

Published information on the Cambrian and Precambrian of southern Alberta is indeed limited. It is based on the geological record exposed in the Front Ranges of the Rocky Mountains and in the Little Rockies of northern Montana (about 100 miles southeast of the southeast corner of Alberta), and on wells drilled into the subsurface.

In southern Alberta, between the International Boundary and Twp. 35 (about the latitude of Red Deer) – an area of 40,000 square miles, only three wells have reached the Precambrian and only 25 wells have reached the top of the Cambrian. Another basement test lies just east of the Alberta-Saskatchewan boundary (Fig. 1).

In the Interior Plains, Cambrian strata lie directly on a crystalline basement complex of pre-Beltian age; in the Lewis thrust sheet of southwestern Alberta, Precambrian strata of Beltian age are exposed; while in the Banff Park area and in southeastern British Columbia, a still younger series of Precambrian strata, the Hector-Corral Creek and Horsethief Creek-Toby formations, is exposed. As outlined in the tentative Geologic Time Table for Southern Alberta (Table I), these Precambrian formations consist of three main age groups: (1) the Lipalian System, (2) the Beltian System, and (3) the pre-Beltian crystalline basement complex.

TABLE I

TENTATIVE REVISED GEOLOGIC TIME TABLE FOR SOUTHERN ALBERTA*

Geologic Time	Stratigraphic Unit	Remarks	Age in millions of years
POSTLIPALIAN DIVISION			
Palaeozoic Era			
Middle Devonian	Elk Point		< 300
Major unconformity with considerable topographic relief			
Silurian Ordovician Upper Cambrian		Removed in west half of Alberta	
Middle Cambrian			
Lower Cambrian		Absent by onlap in Alberta Plains and Front Ranges	< 500
Unconformity with slight topographic relief			
PRECAMBRIAN DIVISION			
Eozoic Era			
Lipalian	Hector-Corral Creek (Horsethief Creek - Toby)		500-800
Major unconformity with considerable topographic relief			
Beltian	Purcell series (Belt series)		800-1200
Profound unconformity			
Pre-Beltian	Basement complex. Undifferentiated crystalline, igneous and metamorphic rocks.		1200-1600

* A new geologic time classification has been adopted for the Precambrian and the old conventional terms — Proterozoic, Algonkian, *et cetera*, have been discarded. In this paper, pre-Beltian formations have not been differentiated.

A complete sequence of Cambrian strata, from lowest Lower Cambrian up through Middle and Upper Cambrian is exposed in the Canadian Rockies. These lie unconformably on the Hector formation in the vicinity of Lake Louise. In the Front Ranges of the Bow Valley, Middle Cambrian strata are exposed in the McConnell thrust sheet, while in the Waterton Lakes area, remnants of Middle Cambrian lie directly on the Beltian. The total aggregate thickness of Cambrian strata exposed in the Canadian Rockies is estimated to exceed 10,000 feet; the Lipalian 5,000 to 6,000 feet; and the Beltian in excess of 15,000 feet.

In the subsurface of the Plains, Cambrian strata are believed to have a maximum thickness of about 1,800 feet, and are largely Middle and Upper Cambrian age, Lower Cambrian being absent by onlap except possibly in the deeper part of the Alberta basin west of Red Deer where there has been no deep drilling. Throughout a large part of southern Alberta, pre-Devonian ero-

sion has removed the overlying Silurian and Ordovician and much of the Upper Cambrian, so that in a large part of the area, Middle Devonian lies directly on Middle Cambrian.

Precambrian Division

Pre-Beltian Basement Complex. — The subsurface Precambrian rocks of the Interior Plains have recently been reported on by R. A. Burwash (1957). This basement complex consists almost entirely of coarse plutonic igneous and metamorphic rocks and schists similar to those exposed in the Canadian Shield. The results of age determinations suggest that all the basement rocks of southern Alberta belong to one tectonic province or georogen†, having an age of approximately 1,200-1,600 million years. These are here referred to as the pre-Beltian basement complex, and are a part of Burwash's Peace River Province. The structural grain within this province is believed to be northwest, in contrast to the northeast trend exposed in the Canadian Shield.

The following are the deep wells which reached the basement in or adjacent to southern Alberta.

Name of well	*Location*	*Depth in feet (subsea)*
Imperial, Provost No. 2	Twp. 37, Rge. 3 W.4 M.	6,968 (−4,546)
Cal. Std., Princess C.P.R.-1	Twp. 20, Rge. 12 W.4 M.	6,147 (−3,705)
Cal. Std., Parkland 4-12	Twp. 15, Rge. 27 W.4 M.	11,793 (−8,484)
Int. Pete., Blood Indian 1	Twp. 8, Rge. 22 W.4 M.	8,975 (−5,863)
Mobil, No. Richmond 31-1 (Sask.)	Twp. 18, Rge. 28 W.3 M.	7,420 (−4,899)

All drilling to date indicates a complete absence of the younger Precambrian rock systems (Lipalian and Beltian) in the Interior Plains.

EOZOIC ERA

The Eozoic era is here defined as the youngest Precambrian era immediately preceding the Palaeozoic era, from which it is separated by the world-wide unconformity at the base of the Cambrian. It is known to contain a very primitive fauna and was a plant world of the lowest type. The name Eozoic, meaning "dawn of life", was first used by Sir William Dawson (1868) who proposed it for the "age of *Eozoon canadense*". It is characterized by a widespread development of Cryptozoans. It is divided into two periods — Lipalian, and Beltian. The pioneer work by Walcott (1928) and the Fentons (1937), has resulted in the discovery, description, and figuring of a primitive fauna from the Beltian of Montana. To date, there is no known fauna from the younger Lipalian system.

The Beltian System. — In southwestern Alberta, in the Waterton Lakes area, the Lewis thrust brings to the surface a thick series of younger Precambrian strata which lie unconformably beneath Middle Cambrian fossiliferous formations. These Precambrian rocks have been mapped by R. A. Daly (1912), G. S. Hume (1933) and C .O. Hage (1943), and by W. H. W. Clow and M. B. B. Crockford (1951), and are assigned to the Purcell series of southeastern British Columbia. They correlate with the Belt series of Montana and Idaho, and were originally named the Lewis series by Daly. Some 15,000 feet of strata are exposed. In summary, they consist of the formations listed in Table II.

The Altyn correlates with the Aldridge, and age determinations (Cumming *et al.*, 1955) on the lead of the Sullivan mine suggests an age of approximately 1,000 million years. Recent dating by Eckelmann *et al.* (1956) on pitchblende from the sunshine mine in Idaho, gives an age of 1,200 million years.

† An orogen is defined as ". . . a regional unit involved in mountain-making" — Rice. A georogen is considered to be a tectonic unit of continental proportions (Gussow, 1957).

TABLE II

PURCELL SERIES OF SOUTHWESTERN ALBERTA

		Overlying formation: Middle Cambrian	
Kintla	3750′	Mem. 4 – Grey argillites (3 sills)	2000′
		3 – Red quartzites	400′
		2 – Grey-green argillites	150′
		1 – Red argillites and quartzites	1200′
Sheppard	600′	Yellowish white limestone, quartzite, argillite.	
Purcell	300′	Lava – dark greenish-purplish amygdalloidal basalt.	
*Siyeh	3200′	Yellowish weathering limestone, some quartzite and argillite.	
Grinnell	1025′	Red argillites, bands of quartzite.	
Appekunny	2020′	Hard thick gritty limestone, quartzite, argillite, sandstone.	
*Altyn	3500′	White to light grey limestone, quartzite, argillite.	
Waterton	1000′+	Thin-bedded dolomite and argillite, grey, brown, purple.	
		Base covered	

* The top bed of the Altyn contains Cryptozoans in abundance. A 40′-50′ limestone member near the base of the Siyeh is composed wholly of Cryptozoans.

In the type area of the Purcell Range, the Purcell series is divided into the following formations:

Upper Purcell { Mount Nelson, Roosville, Phillips, Gateway

Purcell - Lava

Lower Purcell { Siyeh, Kitchener, Creston, Aldridge (Host rock of Sullivan Mine at Kimberley), Fort Steel

Since the Belt strata were first described in 1869, they have been assigned, alternately, to the Cambrian and the Precambrian. This is understandable as they carry no diagnostic fossils and are almost unmetamorphosed. Since 1910, however, they have been regarded as Precambrian age by most geologists. In 1898, Walcott (1899) made a general study of the Belt in the Big and Little Belt Mountains and concluded that a great stratigraphic unconformity separates the Cambrian and Belt, with 3,000 to 4,000 feet of Belt strata being eroded.†

Among the fauna described from the Belt series of Montana are an inarticulate brachiopod *Lingulella montana* Fenton and Fenton, radiolaria, phtanites, worm tracks and borings, and six new genera and ten new species of *Collenia.*

The Lipalian System. – Further north in Banff National Park, the Castle Mountain thrust brings a still younger series of Precambrian strata to the surface. These are the Hector and Corral Creek formations of the Bow Valley, and underlie the Lower Cambrian with a gentle angular unconformity that locally appears conformable. The Hector and Corral Creek correlate with the Horsethief Creek and Toby of southeastern British Columbia, which were originally recognized and described by J. F. Walker (1926) of the Geological Survey of Canada, and placed in his Windermere series of Late Precambrian age. It is interesting to note that Walker does not use the term "Proterozoic".

† Later work by Fenton and Fenton (1937) postulates some 20,000 feet of Beltian strata to have been eroded before Middle Cambrian Time.

In southeastern British Columbia, the Horsethief Creek and the basal Toby conglomerate lie on the Purcell series with a considerable angular unconformity, and are unconformably overlain by Lower Cambrian. A basal conglomerate is also developed at the base of the Cambrian. The total thickness of the Lipalian may exceed 5,000 feet in southeastern British Columbia, and in Banff National Park, sections of more than 2,000 feet have been measured, with the base nowhere exposed. The Lipalian is absent in the Waterton Lakes area and in Montana .

In general, the Lipalian rocks consist of grey, green, and purple siliceous shales and argillites, with interbedded conglomerate bands and thin rhythmically bedded limestone members. One of the best geological markers in Banff Park is the Mount Temple limestone member, which is 20 feet thick and exhibits a characteristic varve-like rhythmic bedding. The limestone is light dove-grey in colour and is interbedded with thin silty beds. The Mount Temple limestone immediately overlies the Taylor Lake purple shale member which is 190 feet thick and is readily recognized wherever exposed. The Mount Temple limestone member is believed to correlate with the Nakimu limestone member of the Horsethief Creek formation of southeastern British Columbia.

The Corral Creek formation is considered to be a basal member of the Hector formation, and the equivalent of the Toby conglomerate of British Columbia. In the type area of Corral Creek, it consists of quartzites and coarse grained sandstone with shale interbeds, and is in excess of 1,300 feet thick.

There is no known fauna in the Lipalian.

Postlipalian Division

"Postlipalian" is proposed for the geologic time since the Lipalian. As such, it represents the complete fossil record since the beginning of Cambrian time. It consists of three well-established eras — the Palaeozoic, the Mesozoic, and the Cenozoic, each of which has been subdivided into several periods which are classic.

Postlipalian is considered to be of equal rank to Precambrian and although it embraces the last 500 million years or so of the geologic record, it represents only about one seventh of geologic time.

PALAEOZOIC ERA

The Cambrian System. — The Cambrian system represents the oldest rocks with a diagnostic fossil record. Everywhere throughout the world, Cambrian strata appear to lie on Precambrian formations unconformably. In most places, the age of the limiting beds at this unconformity is widely separated, and a lost geological record up to 2,000 million years is possible.

In the subsurface of southern Alberta, Middle Cambrian strata ($<$500 m.y.) lie with profound unconformity on a crystalline basement complex of pre-Beltian age, estimated to be 1,200 to 1,600 million years old. In the Waterton Lakes area, a thin Middle Cambrian section lies unconformably on rocks of the Beltian system which is estimated to be not much more than 800 million years old, while in the Lake Louise area, the time break is considerably less. Recent mapping by J. E. Reesor (personal communication) of the Geological Survey of Canada, indicates that about 100 miles further west in the Lardeau area of British Columbia, the Cambrian and the Precambrian (Lipalian) Horsethief Creek may be conformable.

An eastward onlap and transgression of Cambrian seas is thus indicated. The Lower Cambrian of the Lake Louise-Bow Valley area varies greatly in thickness, indicating considerable pre-Cambrian topographic relief. Further eastward, the Lower Cambrian is entirely absent by onlap and transgression, except possibly in the deepest part of the Alberta basin west of Red

Deer. Further eastward in Saskatchewan, both the Middle and Upper Cambrian disappear by onlap and the zero depositional edge of the Cambrian is almost a straight line from the southeast corner of Saskatchewan north-northwest to Montreal Lake.

Although the Cambrian formations have been measured and described in several type localities in the Canadian Rockies, essentially no detailed mapping has ever been undertaken. As early as 1887, R. G. McConnell of the Geological Survey of Canada reported on the presence of a Cambrian section in the Rocky Mountains. This was followed by the monumental pioneer work by Walcott, summarized in his posthumous 1928 publication, and by a restudy of several of his type sections by C. F. Deiss (1939, 1940), F. Rasetti (1951, 1956), and many others. On the basis of this work, the Cambrian strata of the mountains have been divided into tentative mappable formational units, and have been assigned to the conventional Lower, Middle, and Upper Cambrian subdivisions (Table III). The careful research work of the Cambrian Sub-

TABLE III

STANDARD TABLE OF FORMATIONS FOR THE CAMBRIAN
BANFF NATIONAL PARK, ALBERTA*

UPPER CAMBRIAN	
	(Top eroded)
Bosworth Formation	
Arctomys Formation	
MIDDLE CAMBRIAN	
Pika Formation	Thin-bedded limestone, dolomite, shale.
Eldon Formation	Thick-bedded tan dolomite.
Stephen Formation	Grey-green shales, thin-bedded limestone.
Cathedral Formation	Limestone, some dolomite and shale.
Mount Whyte Formation	Interbedded silty and limy shales and sandstones.
LOWER CAMBRIAN	
Gog Formation	Peyto limestone member.
	St. Piran quartzite member.
	(Unconformity)
PRECAMBRIAN — *Hector Formation*	

* After Walcott (1928), Rasetti (1951, 1956), and Okulitch (1956).

committee (B. F. Howell *et al.*, 1944), and of Christina Lochman (1956, 1957) and others, has resulted in a faunal zonation of the Cambrian that is of great value for correlation purposes, especially with regard to the little known and unnamed Cambrian formations in the subsurface of the Interior Plains.

J. B. Webb (1951) describes the Cambrian of the Plains as ". . . a rather monotonous sequence of thinly interbedded green and maroon shales, light grey, calcareous, quartz silts, and fine-grained sandstones. The sands are typically glauconitic and the shales micaceous. At the top, local thin conglomerates occur with a few limestone pebbles or weathered chert fragments. Well rounded, frosted quartz grains are common. Limestones become prominent in the formation [westward]. The basal 100-550 feet is generally more sandy, consisting of white,

pink, and red-mottled quartz sandstones with shale interbeds. The sandstones become pebbly and arkosic near the base. The entire formation is marine, containing a small fauna of brachiopods and trilobites; two species of *Dicellomus* are the common fossils . . ."

This sequence is known as the Deadwood formation in Montana. It lies unconformably on a crystalline basement complex and, in the normal sequence, is overlain by fossiliferous strata of Middle Ordovician age. Recently, Lochman and Duncan (1950) discovered a Lower Ordovician fauna in the upper part of the Deadwood in the Black Hills, and R. J. Ross (1957), based on trilobite collections from cores, assigns the upper 350 feet of the Deadwood in the subsurface of eastern Montana, to the Lowei Ordovician.

The Cambrian and Lower Ordovician appear to be conformable and lithologically are inseparable without fossil evidence. Post-Deadwood emergence was slight and was followed by Middle Ordovician deposition which in Saskatchewan is represented by the Winnipeg formation. In post-Silurian time, deformation caused folding and faulting in the Canadian Rockies, and deep erosion and truncation removed the Ordovician and Silurian, and the Upper Cambrian in the western half of southern Alberta, and north of Edmonton completely removed all Early Palaeozoic strata. As a result, the Middle Devonian (Elk Point formation) rests directly on older formations with considerable topographic relief and which range in age from the Pre-Beltian basement complex to Middle Cambrian, Upper Cambrian, Ordovician and Silurian. This sub-Devonian unconformity represents one of the greatest breaks in the geological record of the Palaeozoic era in North America.

Table IV is a generalized descriptive log of the Cambrian lithology encountered in California Standard, Parkland 4-12, compiled from Canadian Stratigraphic Service Limited, sample log No. 809, and checked against McCullough Tool Company, radiation scintillometer log No. 17681 (Fig. 2). This well was completed April 17, 1955, at a depth of 11,836 feet, and penetrated 1,223 feet of Cambrian section. Palaeontological information on the cores has not been released but the lithology and thickness check fairly closely with the Front Range outcrop section and may be assumed to be Middle Cambrian (?). The interval 10,570′-10,650′ is here tentatively assigned to the Eldon formation; the interval 10,650′-10,835′ to the Stephen formation; the massive limestone interval 10,835′-11,525′ to the Cathedral formation; and the lower interval 11,525′-11,793′ to the Mount Whyte.

F. A. McKinnon (1942) studied the Cambrian section in the Front Range in the Bow Valley (Twp. 24, Rge. 9, W.4th M.). He found 1,477 feet of Cambrian strata exposed, and from a fossil zone about 45 to 60 feet below the unconformity at the top of the section, collected the following:

Brachiopoda	–	*Acrothele* cf. *pentagonensis* Bell
Trilobita	–	*Coelaspis prima*? Deiss
		Ehmania n. sp.
		Ehmaniella n. sp.
		Elrathina sp. indet.
		2 n. gen. (one close to *Solenopleurella* *Thompsonaspis* or n. gen.)

All but *Ehmaniella* occur in Middle Cambrian of northwestern Montana. *Ehmaniella* occurs in the Middle Cambrian of Utah and in the Stephen formation of Castle Mountain (Mount Eisenhower), Alberta.

The following Cambrian fossils have been reported from wells drilled in southern Alberta:-

Imperial, Provost No. 2: 1-33-37-3 W.4th M. (McGehee, 1949)

Dicellomus cf. *D. occidentalis* Bell
Dicellomus cf. *D. amblia* Bell
Linnarssonella sp.
(Identifed by C. W. Bell as lower Upper Cambrian age)

Cal. Std., Princess C.P.R. 1: 13-22-20-12 W.4th M. (F. K. Beach, 1950).

Dicellomus sp.
(Identified by Edwin Kirk as Upper Cambrian age)

Commonwealth No. 1: 8-9-3-15 W.4th M. (F. K. Beach, 1950)

Obolus mcconnellii (at 5,220′)
(Identified by P. S. Warren. Is a Middle Cambrian fauna found in the Stephen and Eldon of the Castle Mountain section).

TABLE IV

GENERALIZED LITHOLOGY OF CAMBRIAN SECTION IN CALIFORNIA STANDARD PARKLAND 4-12

(Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W.4th M.)

MIDDLE DEVONIAN			
10,408′-10,570′	(162′)	*Ghost River Fm.*	Tan to pink dolomite anhydrite, shale, *etc.*
		(Strong erosional unconformity)	
MIDDLE CAMBRIAN (?)-(1,223′)			
10,570′-10,650′	(80′)	*Eldon Fm. (?)*	Limestone, grey, brown to tan, dense, argillaceous, dolomite.
10,650′-10,835′	(185′)	*Stephen Fm. (?)*	Shale, green, very fine, micaceous, shaly limestone interbeds, *Obolus.*
10,835′-11,525′	(690′)	*Cathedral Fm. (?)*	
-11,195′	(360′)		Limestone, grey, brown to greenish grey, dense, becoming shaly towards base, oolitic.
-11,280′	(85′)	*(Albertella zone?)*	Shale, green very fine micaceous, fossiliferous, *Trilobites* and *Lingula.*
-11,525′	(245′)		Limestone, green, brown to greenish grey, dense, trace glauconite, fossil fragments, *Lingula?* fossiliferous at 11,450′.
11,525′-11,793′	(268′)	*Mt. Whyte Fm. (?)*	
-11,700′	(175′)		Shale, green, very fine, micaceous, fossil fragments, fossiliferous.
			Shale, brown, becoming green, sandy to silty, fossiliferous.
-11,793′	(93′)		Sandstone, grey to green, fine to coarse, basal conglomerate.
		(Profound Unconformity)	
PRECAMBRIAN (pre-Beltian basement complex)			
11,793′-11,836′	(43′)		Schist, green, grey to dark to black, biotite.

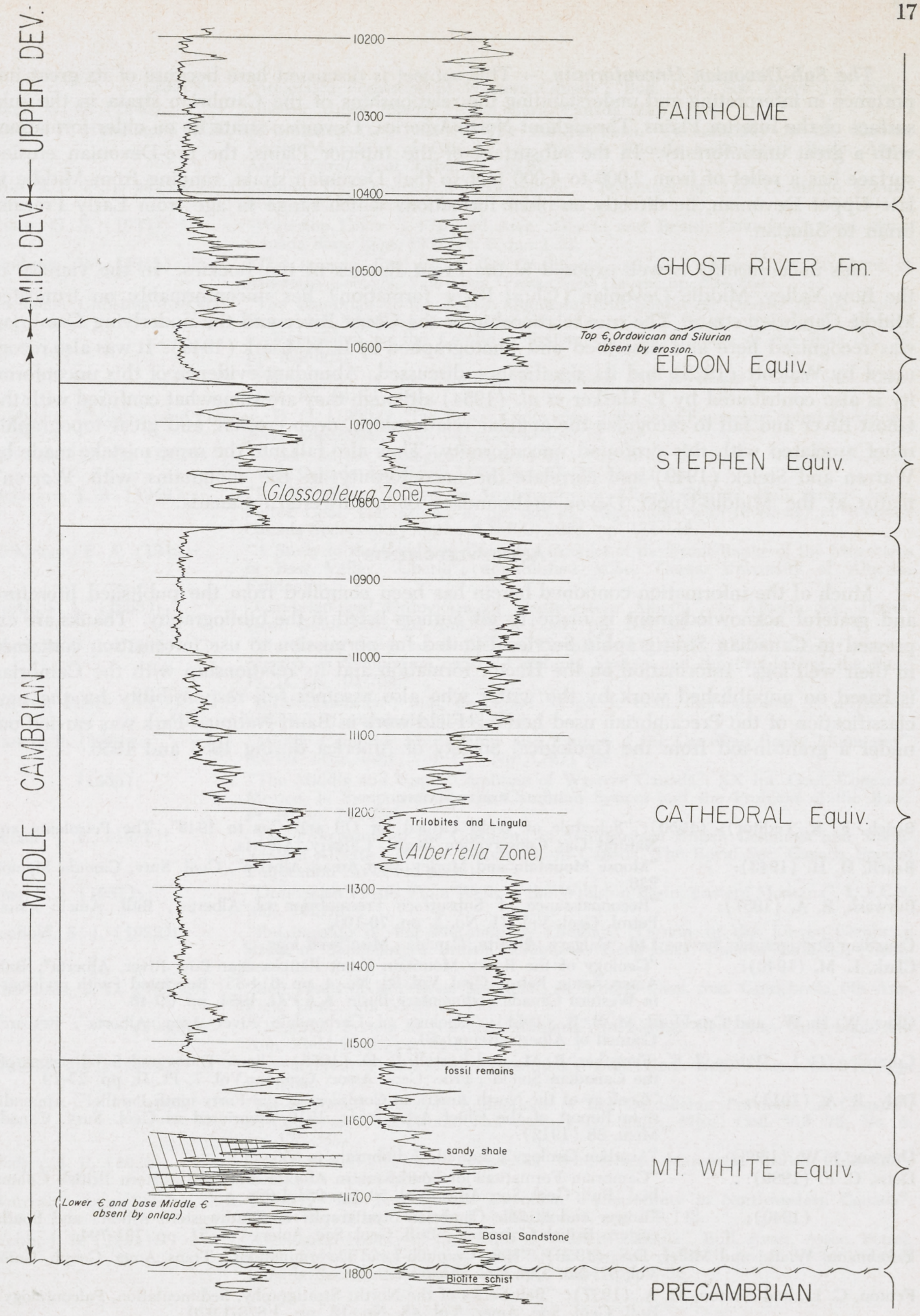

FIGURE 2.

GEOLOGICAL INTERPRETATION OF CAMBRIAN SECTION IN CALIFORNIA STANDARD PARKLAND 4-12

McCullough Tool Company, radiation scintillometer log No. 17681, with geological interpretation based on a reinterpretation of Canadian Stratigraphic Service Limited sample log No. 809.

The Sub-Devonian Unconformity. – This subject is discussed here because of its great importance in interpreting and understanding the relationships of the Cambrian strata in the subsurface of the Interior Plains. Throughout North America, Devonian strata lie on older formations with a great unconformity. In the subsurface of the Interior Plains, the pre-Devonian erosion surface has a relief of from 2,000 to 4,000 feet so that Devonian strata, ranging from Middle to late Upper Devonian, lie directly on older formations which range in age from Early Precambrian to Silurian.

This unconformity is well exposed in the Front Ranges of the Rockies. In the vicinity of the Bow Valley, Middle Devonian (Ghost River formation) lies unconformably on truncated Middle Cambrian strata. The true relationship of the Ghost River and the underlying Cambrian was recognized here and described and photographed by L. M. Clark (1949). It was also recognized by Walcott (1928) and its significance discussed. Abundant evidence of this unconformity is also contributed by P. Harker *et al.* (1954) although they are somewhat confused with the Ghost River and fail to recognize the angular relationships, deep erosion, and great topographic relief asociated with this profound unconformity. They also fall into the same mistake made by Warren and Stelck (1949) and correlate the unconformity in the mountains with Warren's hiatus at the Middle-Upper Devonian boundary of northwestern Canada.

Acknowledgments

Much of the information contained herein has been compiled from the published literature and grateful acknowledgment is made to all authors listed in the bibliography. Thanks are expressed to Canadian Stratigraphic Service Limited for permission to use information contained in their well logs. Information on the Hector formation and its relationship with the Cambrian is based on unpublished work by the writer who also assumes full responsibility for the new classification of the Precambrian used herein. Field work in Banff National Park was carried out under a grant-in-aid from the Geological Society of America during 1955 and 1956.

Bibliography

Beach, F. K. (editor); (1950): "Schedule of Wells Drilled for Oil and Gas to 1949", The Petroleum and Natural Gas Conservation Board, Calgary, Alberta.

Beach, H. H. (1943): "Moose Mountain and Morley Map Areas, Alberta", Geol. Surv. Canada Memoir 236.

Burwash, R. A. (1957): "Reconnaissance of Subsurface Precambrian of Alberta", Bull. Amer. Assoc. Petrol. Geol. Vol. 41, No. 1, pp. 70-103.

Canadian Stratigraphic Service Ltd., Calgary, Alberta, Canada. Misc. well logs.

Clark, L. M. (1949): "Geology of the Rocky Mountain Front Ranges near Bow River, Alberta", Bull. Amer. Assoc. Petrol. Geol. Vol. 33, No. 4, pp. 614-33. Reprinted (with revisions) *in* Western Canada Sedimentary Basin, A.A.P.G. 1954, pp. 29-46.

Clow, W. H. W., and Crockford, M. B. B. (1951): "Geology of Carbondale River Area, Alberta", Research Council of Alberta Report 59.

Cumming, G. L., Wilson, J. T., Farquhar, R. M., and Russell, R. D. (1955): "Some Dates and Subdivisions of the Canadian Shield", Proc. Geol. Assoc. Canada. Vol. 7, Pt. II, pp. 27-79.

Daly, R. A. (1912): "Geology of the North American Cordillera at the Forty-ninth Parallel", Appendix 6 *in* Report of the Chief Astronomer, 1910; Reprinted as Geol. Surv. Canada Mem. 38 (1912).

Dawson, J. W. (1868): "Acadian Geology", 2nd ed., Edinburgh, p. 658.

Deiss, C. F. (1939): "Cambrian Formations of Southwestern Alberta and Southeastern British Columbia", Bull. Geol. Soc. Amer. Vol. 50, pp. 951-1,026.

(1940): "Lower and Middle Cambrian Stratigraphy of Southwestern Alberta and Southeastern British Columbia", Bull. Geol. Soc. Amer. Vol. 51, pp. 731-794.

Eckelmann, W. R., and Miller, D.S. (1956): "New Uranium-Lead Determinations", Trans. Amer. Geoph. Union Vol. 37, No. 3, p. 342. *Abstract.*

Fenton, C. L., and Fenton, M. A. (1937): "Belt Series of the North: Stratigraphy, Sedimentation, Paleontology", Bull. Geol. Soc. Amer. Vol. 48, No. 12, pp. 1,873-1,970.

(1957): "Paleoecology of Precambrian of Northwestern North America," Geol. Soc. Amer. Mem. 67, pp. 103-116.

Gussow, Wm. C. (1956): "Lipalian Interval Evaluated", Bull. Geol. Soc. Amer. Vol. 67, No. 12, p. 1,702. *Abstract.*

(1957): "Athabasca Formation of Western Canada", Bull. Geol. Soc. Amer. (in press).

Hage, C. O. (1940): "Beaver Mines, Alberta", Geol. Surv. Canada Map 739A.

Harker, P., Hutchinson, R. D., and McLaren, D. J. (1954): "The Sub-Devonian Unconformity in the Eastern Rocky Mountains of Canada", *in* Western Canada Sedimentary Basin, Amer. Assoc. Petrol. Geol. Tulsa, pp. 48-67.

Howell, B. F., *et al* (1944); *Chairman,* The Cambrian Sub-committee: "Correlation of The Cambrian Formations of North America", Bull. Geol. Soc. Amer. Vol. 55, No. 8, pp. 993-1,003.

Hume, G. S. (1933): "Waterton Lakes – Flathead Area, Alberta and British Columbia", Geol. Surv. Canada Sum. Rept. 1932, Pt. B, pp. 1-21.

Lindgren, W. (1915): "The Igneous Geology of the Cordilleras and its Problems", *in* Problems of American Geology, Yale Univ. Press, New Haven, pp. 234-286.

Lochman, Christina (1956): "The Cambrian of the Rocky Mountains and Southwest Deserts of the United States and Adjoining Sonora Province, Mexico", XX Int. Geol. Congress, Mexico, *in* Symposium on the Cambrian System and the Problem of the Base, Pt. II, pp. 529-662.

(1957): "Paleoecology of the Cambrian in Montana and Wyoming", Geol. Soc. Amer. Mem. 67, pp. 117-162.

Lochman, Christina, and Duncan, D. C. (1950): "The Lower Ordovician *Bellefontia* Fauna in Central Montana", Jour. Paleontology Vol. 24, pp. 350-353, Pl. 52.

McConnell, R. G. (1887): "Report on the Geological Features of a Portion of the Rocky Mountains", Geol. Surv. Canada An. Rept. 1886,,Vol. II, Pt. D, 41 pp.

McGehee, J. R. (1949): "Pre-Waterways Palaeozoic Stratigraphy of Alberta Plains", Bull. Amer. Assoc. Petrol. Geol. Vol. 33, No. 4, pp. 603-13. Reprinted (with revisions) *in* Western Canada Sedimentary Basin, A.A.P.G. 1954, pp. 131-142.

McKinnon, F. A. (1942): "A Study of the Cambrian-Devonian Contact at the Front Range of the Mountains in Bow Valley, Alberta"; unpublished M.Sc. Thesis, University of Alberta, Edmonton.

North, F. K. (1953): "Cambrian and Ordovician of Southwestern Alberta", *in* Alberta Soc. Petrol. Geol. Guidebook, 3rd Ann. Field Conf., pp. 108-116.

Okulitch, V. J. (1956): "The Lower Cambrian of Western Canada and Alaska", XX Int. Geol. Congress, Mexico, *in* Symposium on the Cambrian System and the Problem of the Base, Pt. II, pp. 701-734.

Pruvost, Pierre (1951): "L'Infracambrien", Bull. de la Soc. belge de Geol., de Paleontol. et d'Hydrol., tome LX, fascicule I, pp. 43-65.

Rasetti, F. (1951): "Middle Cambrian Stratigraphy and Faunas of the Canadian Rocky Mountains", Smiths. Misc. Coll., Vol. 116, No. 5, 271 pp.

(1956): "The Middle and Upper Cambrian of Western Canada", XX Int. Geol. Congress, Mexico, *in* Symposium on the Cambrian System and the Problem of the Base, Pt. II, pp. 735-750.

Reesor, J. E. (1957): "The Proterozoic of the Cordillera in Southeastern British Columbia and Southwestern Alberta", *in* The Proterozoic in Canada, The Royal Soc. Canada Special Publication No. 2 (in press).

Ross, R. J. (1957); "Ordovician Fossils From Wells in the Williston Basin, Eastern Montana", U.S.G.S. Bull. 1021M.

Scofield, S. J. (1922): "Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of Southeastern British Columbia", Geol. Surv. Canada Bull. 35 (Geol. Ser. 42).

Theodosis, S. D. (1955a): "Belt Series of Northwest Montana", *in* Billings Geol. Soc. Guidebook, 6th Ann. Field Conf., pp. 58-63.

(1955b): "Cambrian System in Northern Montana", *in* Billings Geol. Soc. Guidebook, 6th Ann. Field Conf., pp. 64-69.

Walcott, C. D. (1899): "Precambrian Fossiliferous Formations", Bull. Geol. Soc. Amer. Vol. 10, pp. 201-208.

(1928): "Pre-Devonian Paleozoic Formations of the Cordilleran Provinces of Canada", *in* Cambrian Geology and Paleontology, V. Smith, Misc., Coll. Vol. 75, No. 5, pp. 175-368.

Walker, J. F. (1926): "Geology and Mineral Deposits of Windermere Map-area, British Columbia", Geol. Surv. Canada Mem. 148.

Warren, P. S., and Stelck, C. R. (1949): "The Late Middle Devonian Unconformity in Northwestern Canada", Trans. Royal Soc. Canada, Vol. 43, Sec. 4, pp. 139-148.

Webb, J. B. (1951): "Geological History of the Plains of Western Canada", Bull. Amer. Assoc. Petrol. Geol. Vol. 35, No. 11, pp. 2,291-2,315. Reprinted (with revisions) *in* Western Canada Sedimentary Basin, A.A.P.G. 1954, pp. 3-28.

THE CROWSNEST VOLCANICS AND CRETACEOUS GEOCHRONOLOGY

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Introduction

The material presented in this paper is a summary of one phase of the geochronologic research which has been carried on at the University of Alberta in collaboration with workers at the Universities of California and Minnesota. Detailed presentations are incorporated in three M.Sc. Theses in the Geology department of the university – by A. J. Beveridge (1956), W. D. Ritchie (1957), G. F. Stansberry (1957) and much of the data has been published elsewhere (Beveridge and Folinsbee 1956, Lipson 1956, Knopf 1956, Folinsbee and Ritchie 1957).

The writers are grateful to collaborators at the University of California at Berkeley and the University of Minnesota for providing the potassium-argon age determinations here reported. J. H. Reynolds and J. Lipson made the determination on Crowsnest volcanics and basal Clearwater glauconite (Lipson 1956). S. S. Goldich and H. Baadsgaard of the Rock Analysis Laboratory at Minnesota made the determination on the Viking glauconite, Ardley bentonite and Coast Range, Bayonne and Itsi batholith micas, not previously reported. P. S. Warren and C. R. Stelck of the University of Alberta have contributed stratigraphic information and read the manuscript critically; their advice and assistance are appreciated. This research work was supported by grants from the Geological Survey of Canada and the General Research Fund of the University of Alberta.

The potassium-argon method of dating may not be sufficently well established to justify attempts to apply it to the resolution of geologic problems concerned with the history of a single geologic period. The data obtained are suggestive and are presented here as a stimulus to further work and a challenge to the more conventional approach (Jeletsky 1956).

The Crowsnest Volcanics

The general stratigraphic relations of the Crowsnest volcanics are well shown in the reconstruction by McKay (1932) (Figure 1). The agglomerates lie on continental Blairmore beds and are overlain by marine shales of the Colorado group. The volcanics and the Blairmore beds below contain an abundant flora related to that in the Cheyenne sandstone of southern Kansas (Berry 1929) now considered to be late Albian in age (McLearn, 1929). The Colorado shale above the volcanics contains the type Cenomanian index fossil *Dunveganoceras* (Stelck personal communication). The extent of the disconformity between the continental volcanics and the marine Colorado shale is not known, though McKenzie (1914) considered the contact conformable, our data suggest an extensive disconformity in terms of time if not of structure.

The petrology of the Crowsnest volcanics has been recorded by J. D. McKenzie (1914) and Rutherford (1938) and the whole Crowsnest problem has recently been critically reviewed by H. S. McKenzie (1956). The feldspar rich agglomerate appears to be waterlain and in certain phases contains abundant fragmental feldspar phenocrysts (Plate 1). This feldspar, which has an orthoclase crystal habit, is for the most part the high temperature variety sanidine, with a very high potash content (13.03% K_2O). Beveridge has studied the heavy accessory minerals in the Crowsnest volcanics (Plate 2) and the heavy mineral suite is a very simple one, comprising only sphene and apatite. It differs markedly from the heavy mineral suites of the Cordilleran intrusives and the late Cretaceous tuffs and bentonites of the plains in the absence of zircon, which is very characteristic of the Cordilleran intrusives, extrusives and effusives (Plate 3).

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Geochronology

Since the feldspar phenocrysts in the Crowsnest volcanics are large (minimizing any diffusion effect), potash rich, and fresh, they comprise an ideal material for potassium-argon age determination. Pure sanidine was separated from a sample of the Crowsnest volcanics, collected west of Coleman, by hand picking and by use of a Frantz magnetic separator. The argon separation and mass spectometric analyses were made by J. H. Reynolds and J. Lipson of the department of Physics, University of California. The ratio of radiogenic A^{40} to radioactive K^{40} in the sample analysed was 0.00504, which yields an age of 96 m.y. (assuming lambda $= 0.51 \times 10^{-9}$ y^{-1} and $R = 0.12$). This figure is in very good agreement with Holmes' time scale B (Figure 2) for the mid-Cretaceous in so far as this can be interpolated from the limited data available.

Cormier (1957) has reported on glauconites from the Sundance formation, lower Upper-Jurassic, of Wyoming, using the strontium-rubidium method. He arrived at ages of 138 and 135 m.y. (± 40) on two determinations. This is in agreement with the Holmes time scale. On the other hand, glauconite which we separated from the McMurray-Clearwater shale contact (basal Clearwater shale, Socony-Vacuum oil sands Well No. 27) gives an A^{40}/K^{40} ratio of 0.00824 and an age of 144 m.y., which is much too great for the Middle Albian to which the upper part of the McMurray has been assigned (Mellon and Wall, 1956). Possibly the glauconite is in this instance derived in part from incompletely assimilated Precambrian clay minerals which retained their radiogenic argon during diagenesis.

Glauconite from the Viking formation in the Armena field of central Alberta, separated by Stansberry (1957) and analyzed at the University of Minnesota Rock Analysis Laboratory gave an A^{40}/K^{40} ratio of 0.00359 and an age of 63 m.y. (lambda $= 0.528 \times 10^{-9}$ y^{-1}, $R = 0.118$). This seems young for a horizon which cannot be younger than lower Cenomanian, and in comparison with the Crowsnest volcanics suggests a long hiatus in the depositional cycle, from 96 to 63 m.y., separating Crowsnest and Viking time. The latest correlation chart issued by the

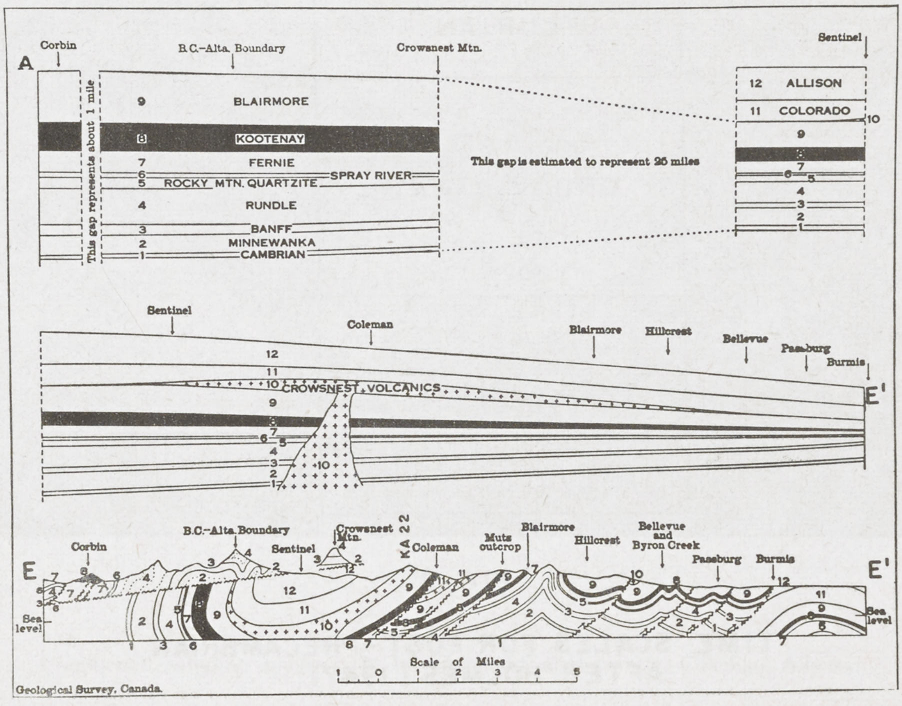

FIGURE 1

Section from Corbin to Burmis before and after the Rocky Mountain Revolution (MacKay, 1932).

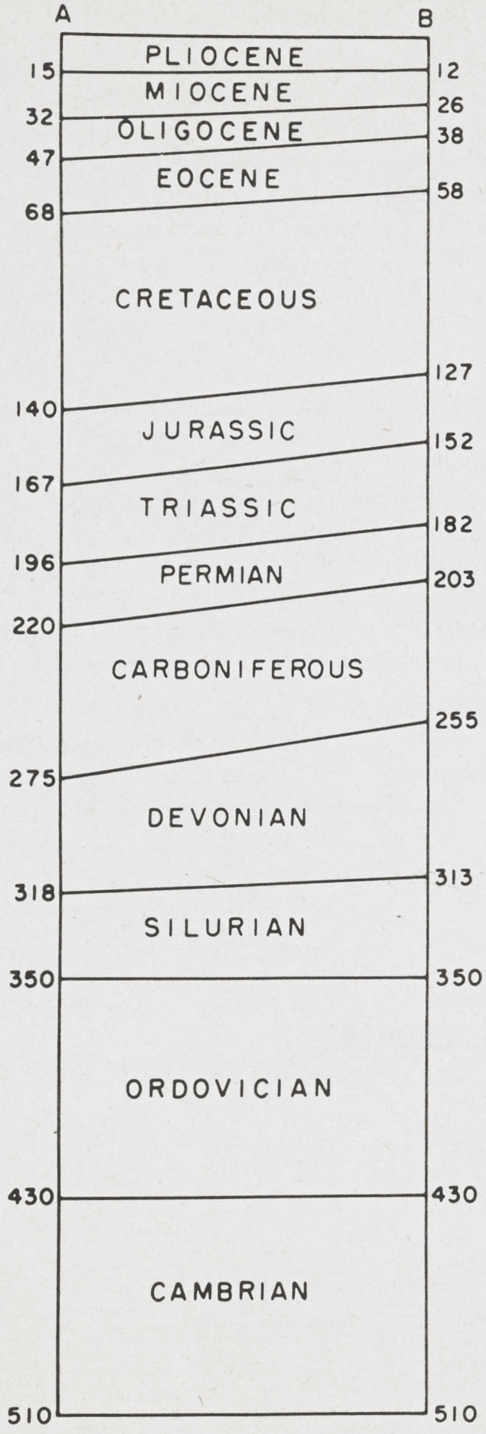

FIG. 2

TIME SCALES FOR POST-PRECAMBRIAN
AFTER HOLMES (1947)

PLATE 1

Fragmental sanidine phenocrysts in Crowsnest agglomerate, Coleman, Alberta.

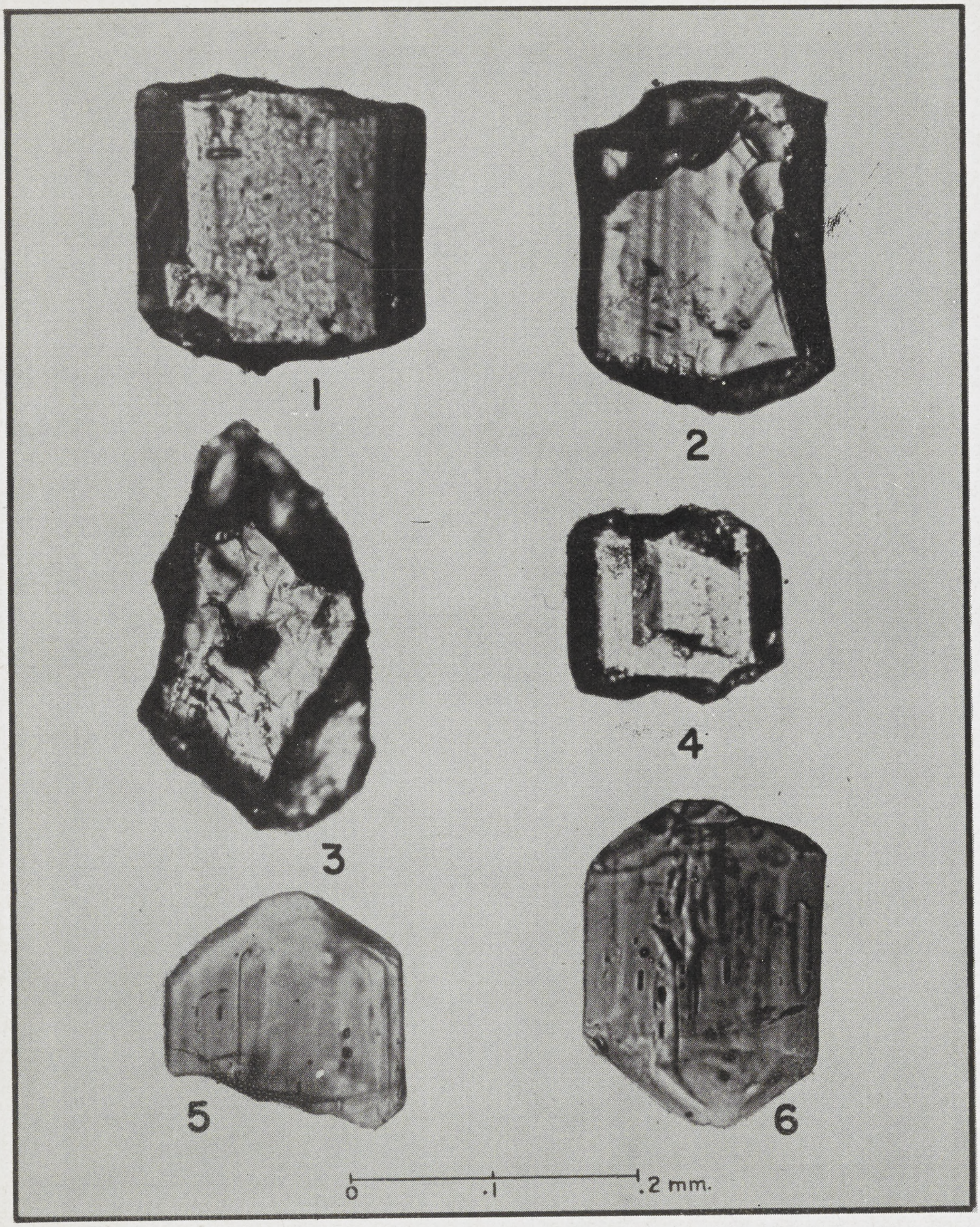

PLATE 2

Crowsnest agglomerate accessory minerals (Beveridge, 1956).

1. Sphene euhedron.
2. Sphene euhedron, conchoidal fracture.
3. Sphene fragment, opaque inclusion and surface fissures.
4. Sphene, envelope habit.
5. Apatite euhedron.
6. Apatite euhedron, inclusions and cavities parallel to *c* axis.

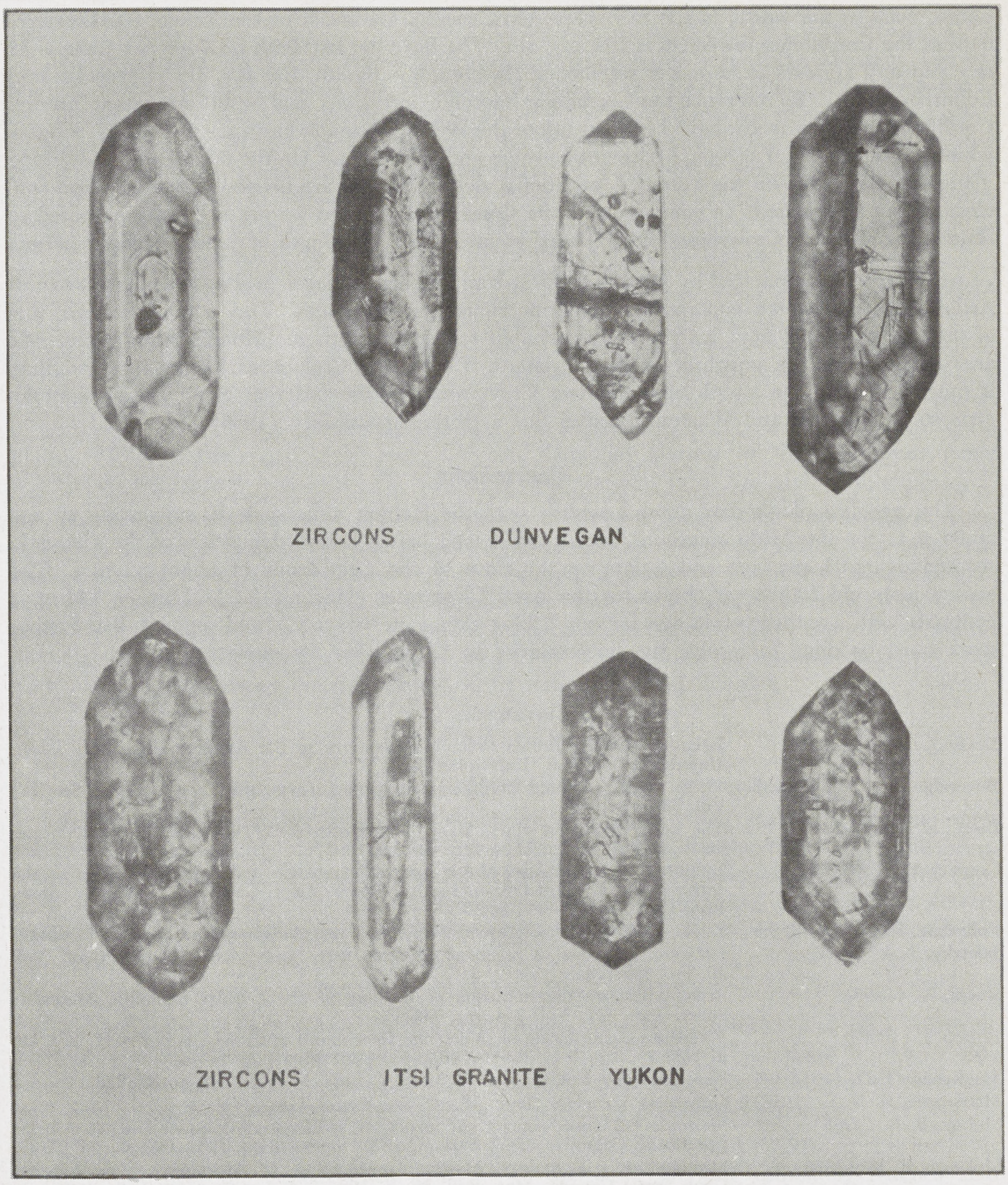

PLATE 3

Euhedral zircon, typical accessory mineral in the Cordilleran intrusives, first appears in the Western Canada basin sediments in sands of upper Cretaceous age, such as the Dunvegan.

Petroleum and Natural Gas Conservation Board of Alberta (1954) correlates these two horizons. We have additional support for the hypothesis of a major time break between the Crowsnest and Viking formations. The main period of igneous intrusion in the Cordillera appears to have occurred at or about Crowsnest time. The Coast Range batholith at Vancouver, the largest batholithic mass in the world, is 105 m.y. years old. The Itsi batholith of the Yukon, northeasternmost of the Cordilleran intrusives is 102 m.y. old. The Bayonne batholith of Kootenay Lake is 82 m.y. old and appears to be a late satellite of the Nelson batholith, 105 m.y. old (Beveridge and Folinsbee, 1956). By inference the Cordilleran plutonic intrusions and uplift attendant on this Cordilleran orogeny might have kept seas out of the Western Canada basin for the 30 m.y. interval which our data suggest as lying between Blairmore and Viking time. On the other hand, the Viking glauconite age may be too young — additional determinations are needed before any firm conclusions can be reached. In common with the Conservation Board we are not quite prepared to officially endorse a Crowsnest-Viking break equal to half the length of the Cretaceous period.

Feldspar was separated by Ritchie (1957) from a bentonite layer in the Ardley coal seam at Ardley, Alberta, which is Lance or uppermost Cretaceous in age. The potassium-argon age of this feldspar is 52 m.y., a figure in reasonable agreement with the Holmes' time scale. We are intrigued by the possibility that the length of the Upper Cretaceous, 11 m.y. by our dating, is much less than the length of the Lower Cretaceous (of the order of 50 m.y.). Paleontologists such as Stelck and Warren consider this a distinct possibility (1956).

Conclusions

Our geochronologic data agree generally with the Holmes time scale B, suggesting an age of 96 m.y. for the Mid-Cretaceous, indicating a long hiatus before deposition of the Colorado sea sediments 63 m.y. ago and a date for the close of the Cretaceous of about 52 m.y. The anomalously old figure we obtain for the basal Clearwater glauconite at McMurray, 144 m.y., contrasts with a rather young age for our Viking glauconite (63 m.y.), and suggests that further work must be done to resolve the uncertainties in telling time by nuclear methods.

References

Beveridge, A. J. (1956): Relation of some British Columbia intrusives to the Alberta sedimentary basin; Unpub. M.Sc. thesis, Univ. of Alberta.

Beveridge, A. J. and Folinsbee, R. E. (1956): Dating Cordilleran orogenies; Trans. Roy. Soc. Canada, Sec. IV, Vol. 50, pp. 19-43.

Berry, E. W. (1929): The upper Blairmore flora, Mesozoic paleontology of Blairmore region, Alberta; Geol. Surv., Canada, Mus. Bull. 58, pp. 55-57.

Cormier, R. F. (1957): Rubidium-strontium ages of the mineral glauconite and their application to the construction of a post-Precambrian time scale; Dept. Geol. and Geophysics, Mass. Inst. Tech., Cambridge, pp. 2-23.

Folinsbee, R. E. and Ritchie, W. D. (1957): Late Cretaceous Geochronology; Canadian Jour. Physics (in press).

Jeletzky, J. A. (1956): Paleontology, basis of practical geochronology; Amer. Assoc. Petrol. Geol., Vol. 40, pp. 679-706.

Knopf, A. (1956): Argon-potassium determination of the age of the Boulder batholith, Montana; Amer. Jour. Sci., Vol. 254, pp. 744-45.

Lipson, J. (1956): Potassium-argon dating of sediments; Geochimica et Cosmochimica Acta, Vol. 10, p. 149.

MacKenzie, J. D. (1914): The Crowsnest Volcanics; Geol. Surv., Canada, Mus. Bull. 4, pp. 1-37.

MacKenzie, H. N. S. (1956): Crowsnest Volcanics; Jour. Alberta Soc. Petrol. Geol., Vol. 4, pp. 70-74.

McKay, B. R. (1932): Mesozoic-Palaeozoic contact and associated sediments, Crowsnest District, Alberta and British Columbia; Geol. Surv., Canada, Summ. Rept. 1932, Part B., pp. 21-67.

McLearn, F. H. (1929): Stratigraphic paleontology, Mesozoic paleontology of Blairmore region, Alberta; Geol. Surv., Canada, Mus. Bull. 58, p. 103.

Mellon, G. B. and Wall, J. H. (1956): Geology of the McMurray formation; Res. Council Alberta, Rept. 72, pp. 10-14, 39-40.

Ritchie, W. D. (1957): The Kneehills tuff; Unpub. M.Sc. thesis, University of Alberta.

Stansberry, G. F. (1957): The Viking formation, Central Alberta; Unpub. M.Sc. thesis, University of Alberta.

Warren, P. S. and Stelck, C. R. (1956): Significance of the Cretaceous fossil succession of Western Canada; International Geol. Congress, Report of 20th Session, Mexico (in press).

THE SWEETGRASS ARCH AREA – SOUTHERN ALBERTA

G. C. WELLS [1]

Introduction

The Sweetgrass Arch is a broad structural feature centered in northern Montana and extending northward into Alberta for at least 150 miles. The Alberta portion of the Arch forms one of the more pronounced structural features in the Western Canadian plains, being equalled in magnitude only by the north portion of the Williston basin to the east. This is illustrated in Figure 1 which is a structure map on the "Base of Fish Scale" horizon, commonly considered as the top of the Lower Cretaceous. This horizon was chosen because of its widespread occurrence and ease of correlation. However, the Arch shows up equally well and is very similar in character on all horizons from Precambrian to Upper Cretaceous.

The term "Sweetgrass Arch", as used in this paper, refers to the structural Arch evident on present-day structure maps, as distinct from the much broader, relatively stable area which separated the Williston basin and the Rocky Mountain geosynclinal belt during much of the Palaeozoic and Mesozoic eras. The Sweetgrass Arch is recognized as being mainly a Tertiary feature, although most workers believe there were earlier counterparts. This paper, by means of a series of isopach maps, outlines the depositional history of the Southern Alberta plains. Although the report area covers only the Canadian portion of the Sweetgrass Arch, it is hoped the isopach maps may shed some light on the history of the Arch as a whole.

The general stratigraphy of Southern Alberta is shown in Figure 2-A. The structural cross-section in Figure 2-B illustrates the present attitude of the sediments across the area, the section running along the north boundary of Township 1 from the foothills to Saskatchewan. It is obvious from the apparent lack of depositional thinning over the Arch, apart from the Jurassic, why this feature is accepted as mainly Tertiary in age. A section on this scale of course might not show minor thinning that could be attributed to earlier movement. However, isopach maps of the various intervals should bring out any related thinning.

Depositional History

CAMBRIAN

Palaeozoic sedimentation began with Cambrian seas encroaching eastward onto the shelf region. Cambrian sediments in the Sweetgrass Arch area are chiefly shales and argillaceous limestones with some sand phases. The isopachs of the total Cambrian (Figure 3) show eastward thinning across the area with an anomalous "thin" straddling the Saskatchewan-Alberta border. This is fairly well removed from and apparently unrelated to the Sweetgrass Arch.

ORDOVICIAN - SILURIAN - MIDDLE DEVONIAN

From Cambrian until Upper Devonian, Southern Alberta constituted part of a relatively positive area separating depositional basins to the east and west. Thus, there is only a thin mantle of sediments representing this time interval. These sediments are lumped together and isopached as one unit because of the minor thicknesses and correlation problems.

The resultant isopach map (Figure 4) shows a gradual eastward thickening that increases in magnitude near the Saskatchewan border. To the west, thinning ultimately reaches zero along a belt trending northward through Calgary. Thickening again takes place to the west of this belt. Although the area as a whole was relatively positive, there is no indication of anomalous uplift coincident with the present Sweetgrass Arch. There is, however, a nosing trend along the southern part of the Saskatchewan border.

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STRUCTURE ON LOWER CRETACEOUS
("BASE OF FISH SCALE" MARKER)

200 MILES

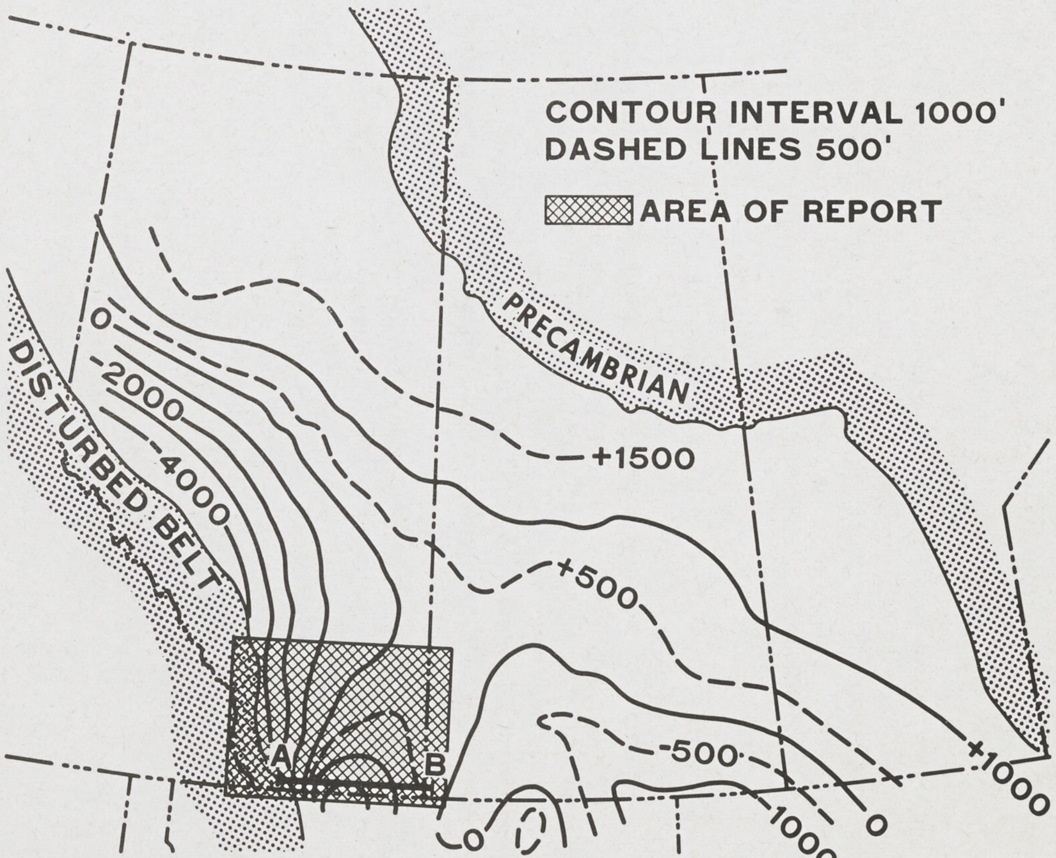


Figure I

MAY 1957

GENERALIZED STRATIGRAPHIC SECTION - SOUTHERN ALBERTA

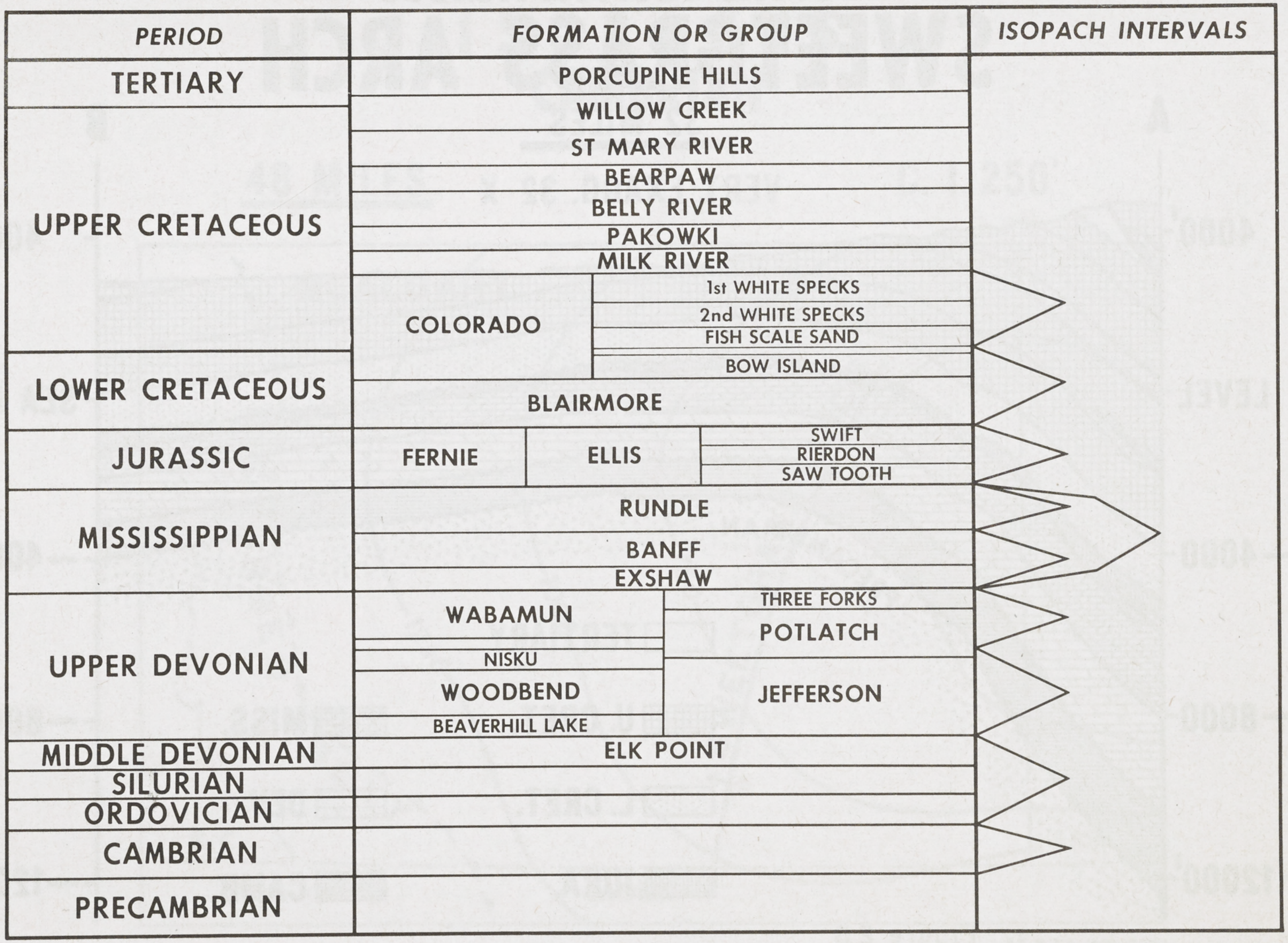
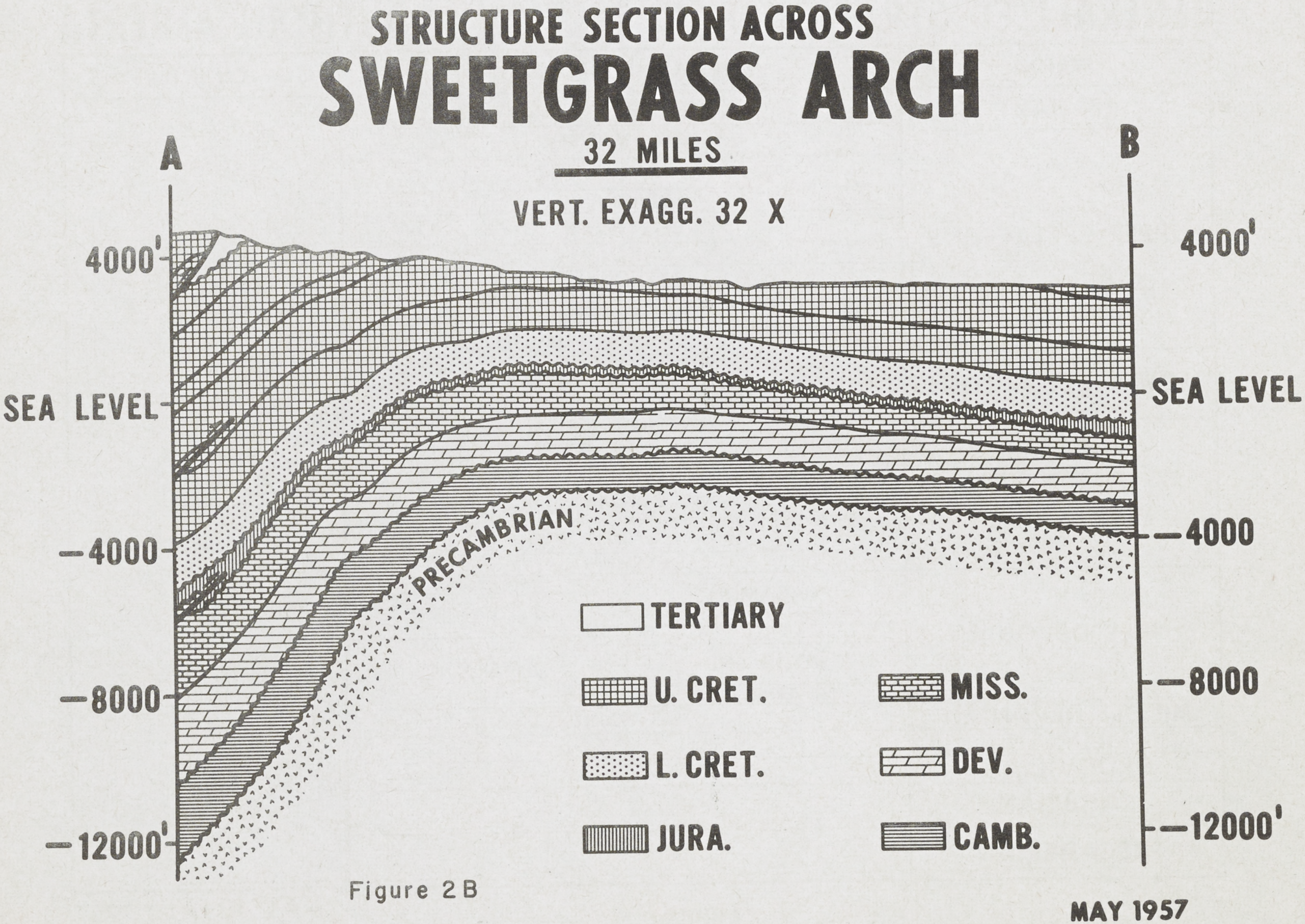


Figure 2 A

MAY 1957



STRUCTURE SECTION ACROSS
SWEETGRASS ARCH
32 MILES
VERT. EXAGG. 32 X
A
B
4000'
SEA LEVEL
-4000
-8000
-12000'
PRECAMBRIAN
TERTIARY
U. CRET.
L. CRET.
JURA.
MISS.
DEV.
CAMB.
MAY 1957

Figure 2B

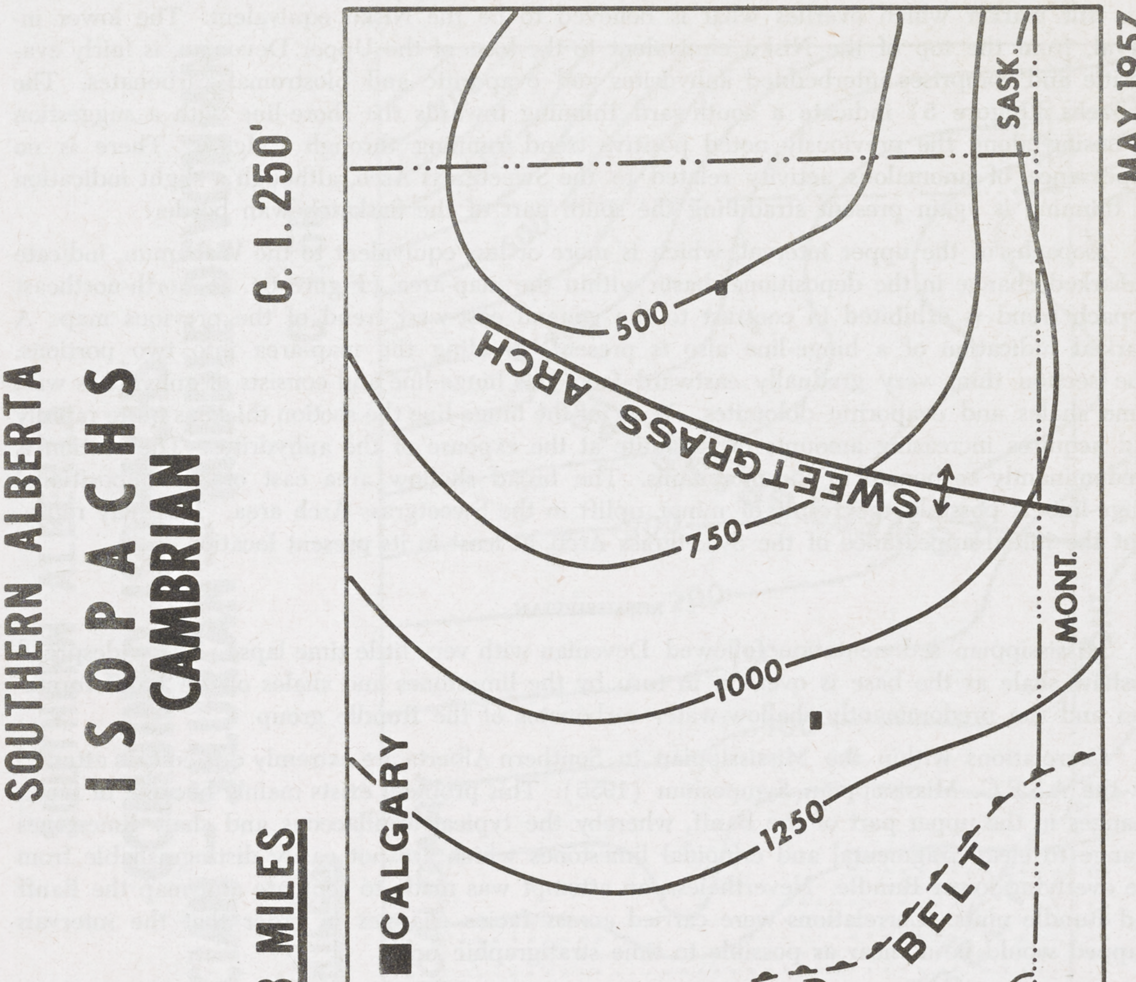

SOUTHERN ALBERTA
ISOPACHS
CAMBRIAN
48 MILES
C. I. 250'
MAY 1957
SASK.
MONT.
B.C.
CALGARY
SWEETGRASS ARCH
DISTURBED BELT
500
750
1000
1250

Figure 3

UPPER DEVONIAN

Upper Devonian time saw seas from the north cover the area once again with a shore-line to the southeast. Variable evaporitic conditions existed in this area throughout most of Upper Devonian time, probably caused by the Killam barrier reef and the biohermal reef chains, basinward to the north.

The Upper Devonian can be divided into two fairly good "time stratigraphic units" by a thin silt marker which overlies what is believed to be the Nisku equivalent. The lower interval, from the top of the Nisku equivalent to the base of the Upper Devonian, is fairly evaporitic and comprises interbedded anhydrites and evaporitic and biostromal carbonates. The isopachs (Figure 5) indicate a southward thinning towards the shore-line with a suggestion of nosing along the previously noted positive trend running through Calgary. There is no appearance of anomalous activity related to the Sweetgrass Arch, although a slight indication of thinning is again present straddling the south part of the Saskatchewan border.

Isopachs of the upper interval, which is more or less equivalent to the Wabamun, indicate a marked change in the depositional basin within the map-area (Figure 6). A north-northeast isopach trend is exhibited in contrast to the general east-west trend of the previous map. A marked indication of a hinge-line also is present, dividing the map-area into two portions. The section thins very gradually eastward from this hinge-line and consists of anhydrites with some shales and evaporitic dolomites. West of the hinge-line the section thickens quite rapidly and acquires increasing amounts of dolomite at the expense of the anhydrites. The section is predominantly carbonate in the mountains. The broad shallow area east of the depositional hinge-line is possibly the result of minor uplift in the Sweetgrass Arch area. This may represent the initial appearance of the Sweetgrass Arch, at least in its present location.

MISSISSIPPIAN

Mississippian sedimentation followed Devonian with very little time lapse. The widespread Exshaw shale at the base is overlain in turn by the limestones and shales of the Banff formation and the predominantly shallow-water carbonates of the Rundle group.

Correlations within the Mississippian in Southern Alberta are extremly difficult, as attested by the A.S.P.G. Mississippian Symposium (1955). This problem exists mainly because of facies changes in the upper part of the Banff, whereby the typical argillaceous and shaly limestones change to clean fragmental and crinoidal limestones which are not easily distinguishable from the overlying lower Rundle. Nevertheless, an attempt was made to separate and map the Banff and Rundle units. Correlations were carried across facies changes in order that the intervals mapped would be as near as possible to time stratigraphic units.

The isopachs of the Banff formation (Figure 7) include the underlying thin Exshaw shale. A gradual northeastward depositional thinning is indicated with a pronounced thick trend extending northeastward across the Arch. Marked erosional thinning is indicated over the north end of the Arch, beyond the pinchout of the overlying Rundle. An area of thinning is also shown straddling the Saskatchewan border, possibly related to the anomalous events indicated on several of the previous maps. Another noticeable depositional thin is located in the southwest part of the map-area.

Isopachs of the Rundle group (Figure 8) show a much more rapid thinning to the northeast but this is due mainly to post-Palaeozoic erosional bevelling rather than depositional thinning. Interpretation of a severely bevelled section such as this is, of course, difficult. The slight thinning over the Sweetgrass Arch is probably erosional and might also be depositional.

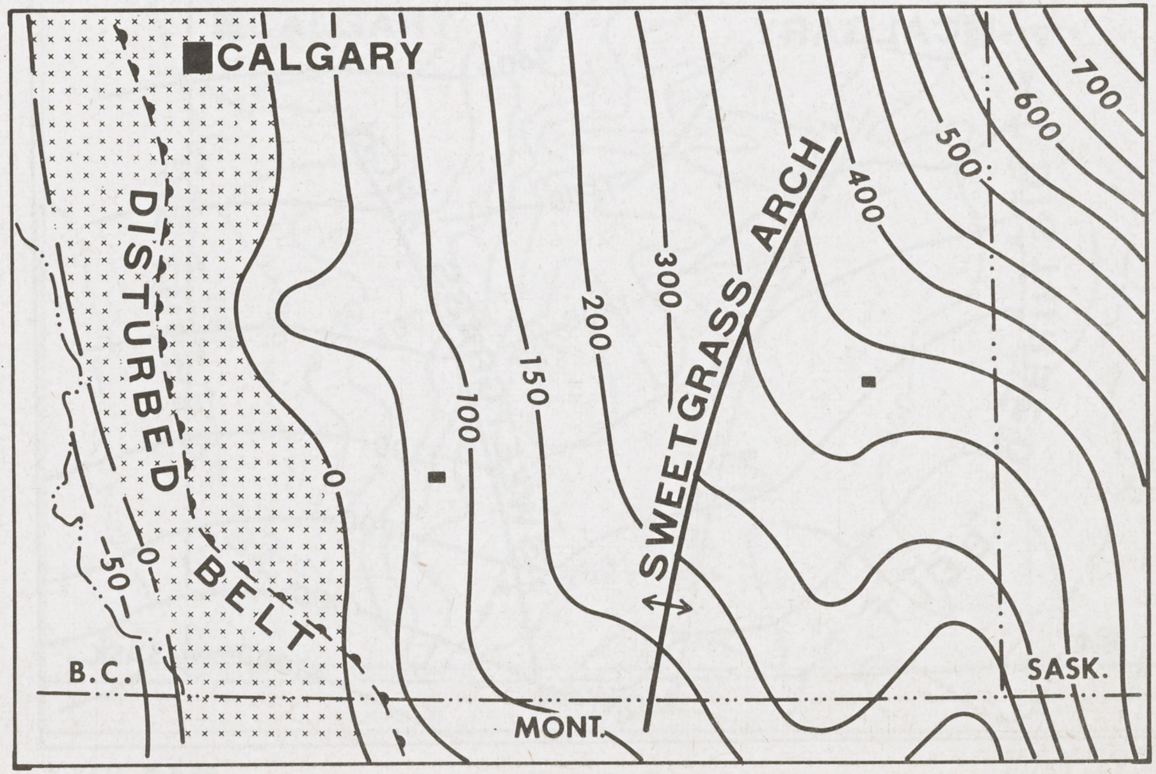
In view of the questionable correlations within the Mississippian in Southern Alberta, a total Mississippian isopach map is also presented (Figure 9). The most noticeable feature is a pronounced thick trend extending eastward across the south part of the Sweetgrass Arch and

SOUTHERN ALBERTA

COMBINED ISOPACHS
ORDOVICIAN — SILURIAN — MIDDLE DEVONIAN

48 MILES

C. I. 50'



MAY 1957

Figure 4

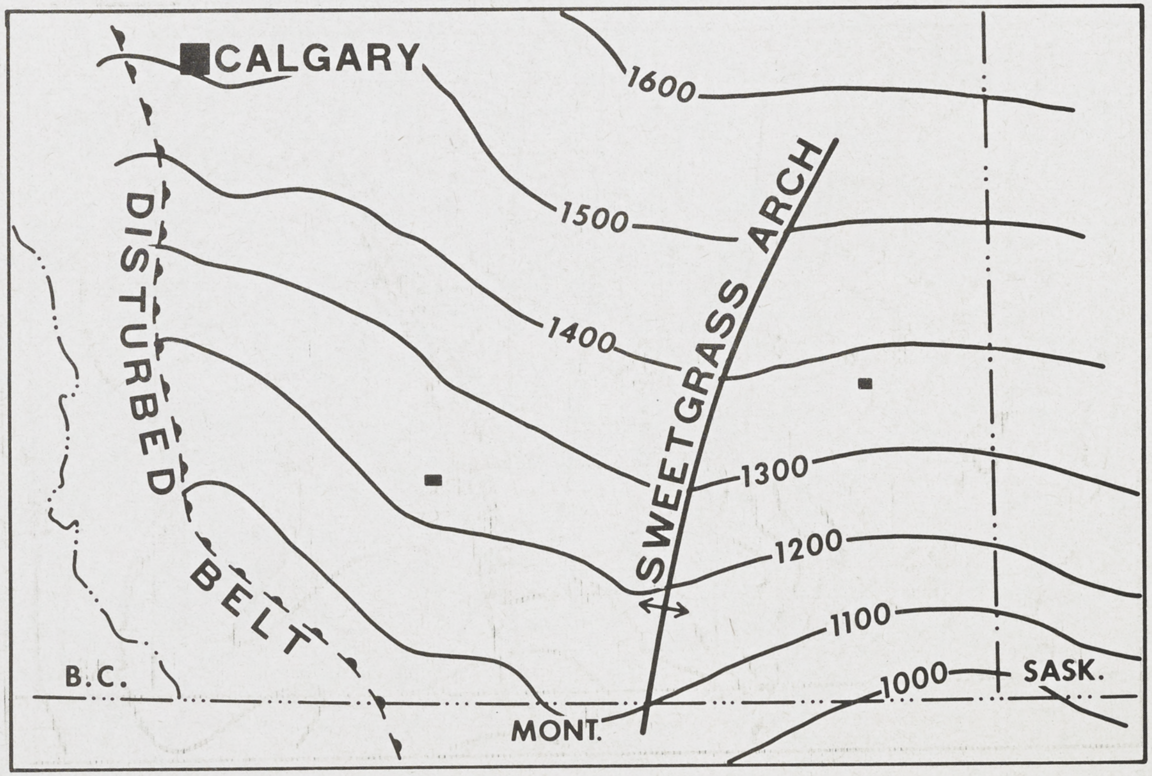
SOUTHERN ALBERTA

ISOPACHS

TOP OF NISKU EQUIV — PRE-UPPER DEVONIAN

48 MILES

C. I. 100'



MAY 1957

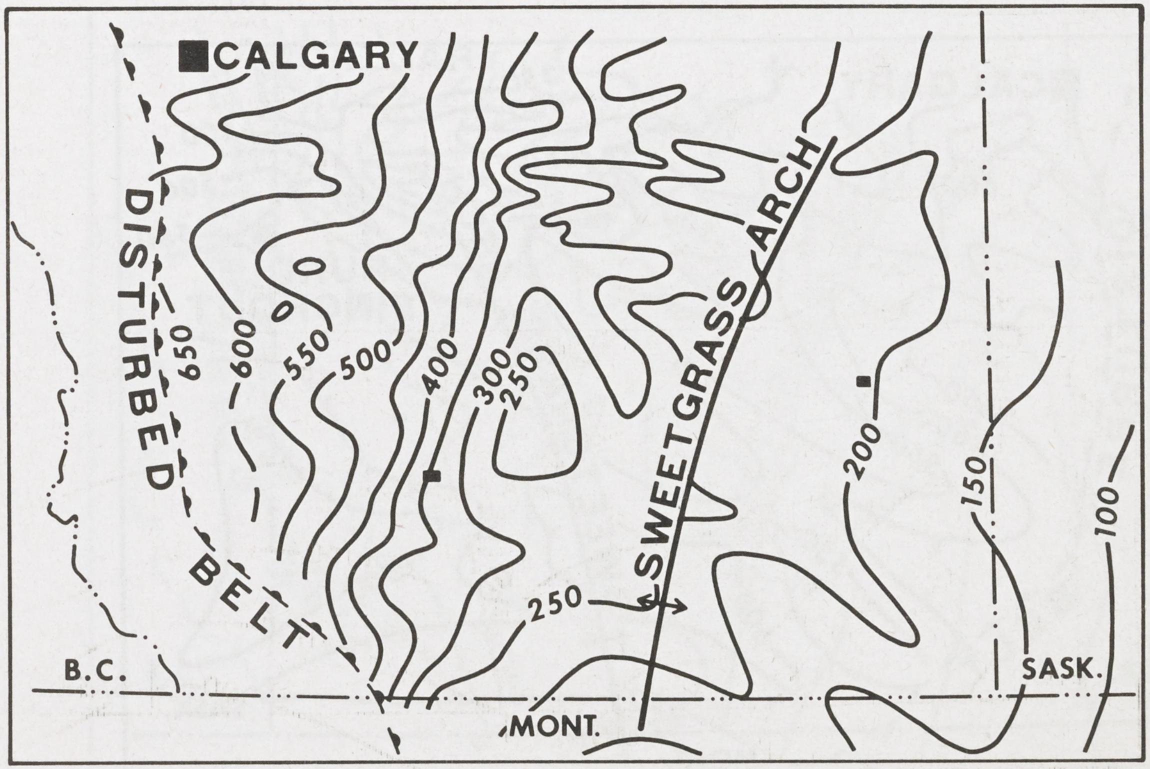
Figure 5

SOUTHERN ALBERTA

ISOPACHS
TOP OF DEVONIAN TO NISKU EQUIV.

48 MILES

C. I. 50'



MAY 1957

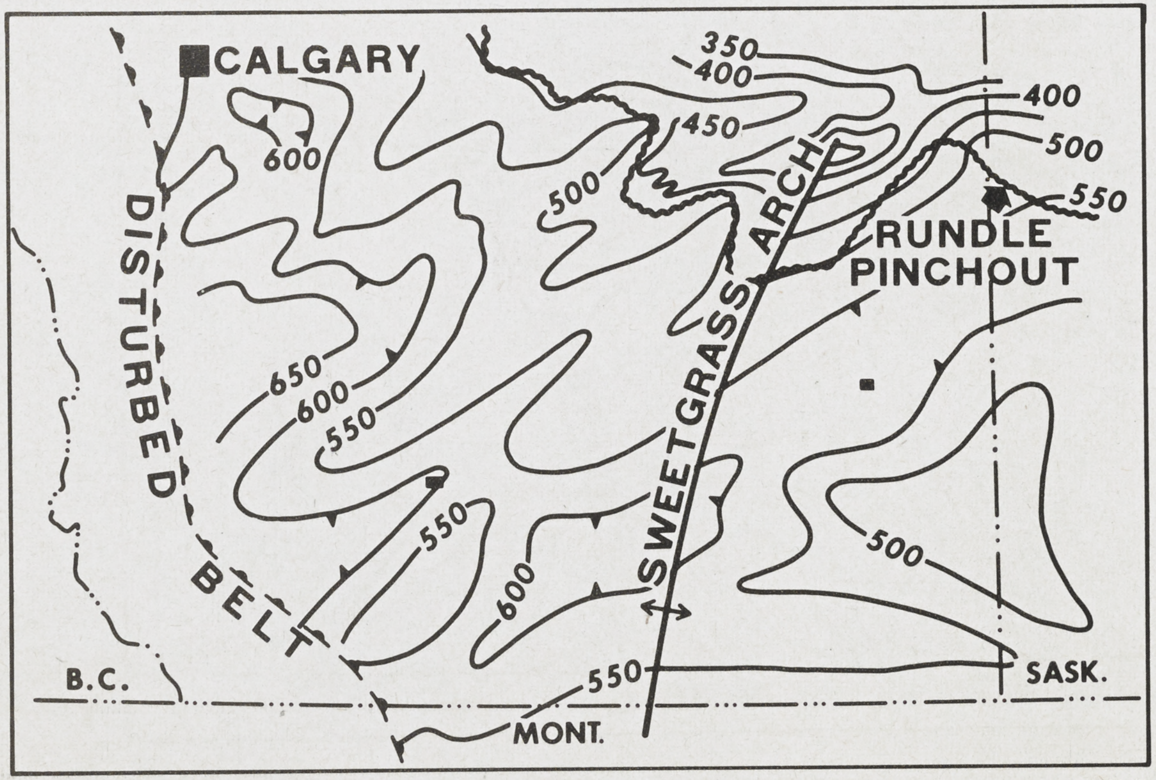
Figure 6

SOUTHERN ALBERTA

ISOPACHS
BANFF FORMATION

48 MILES

C. I. 50'



MAY 1957

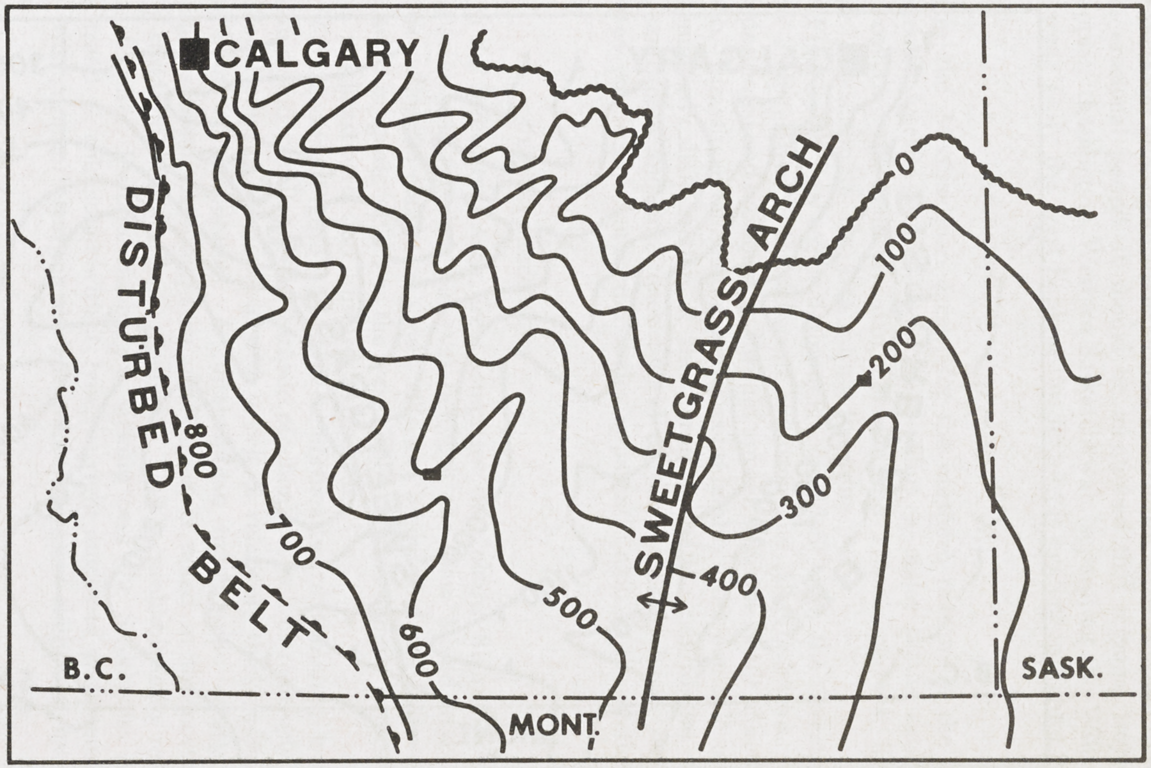
Figure 7

SOUTHERN ALBERTA

ISOPACHS
RUNDLE GROUP

48 MILES

C. I. 100'



MAY 1957

Figure 8

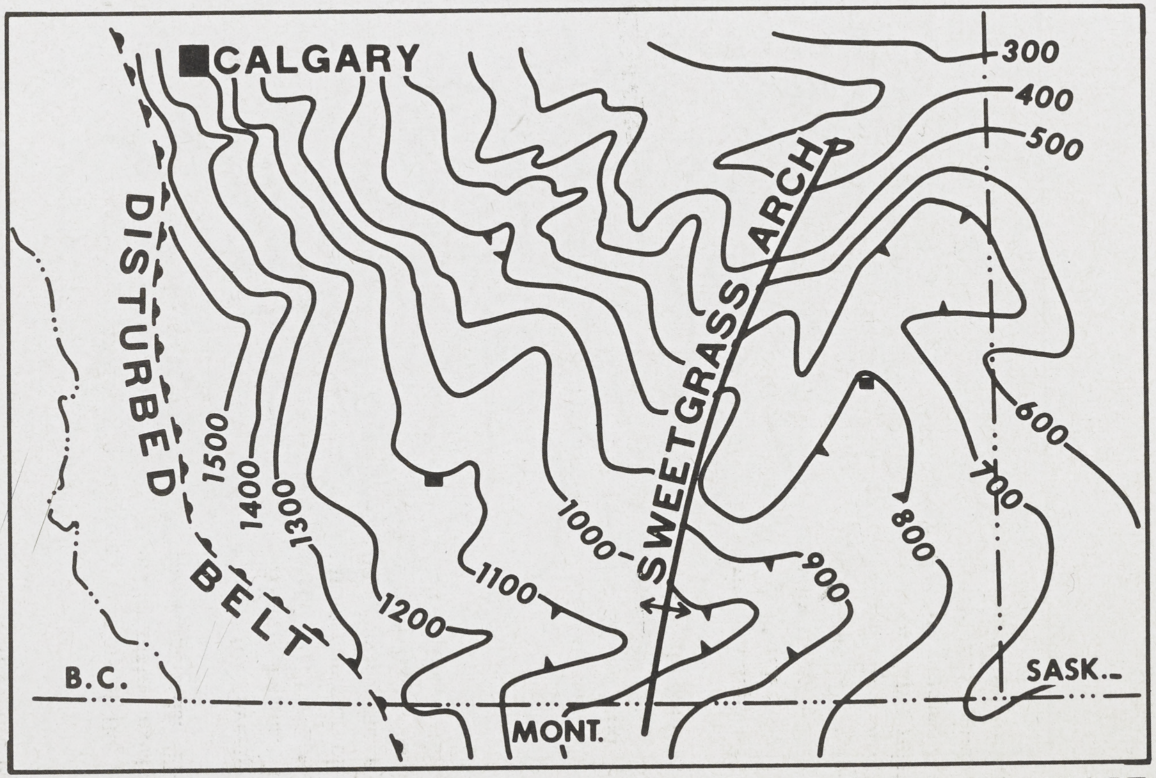
SOUTHERN ALBERTA

ISOPACHS

MISSISSIPPIAN

48 MILES

C. I. 100'



MAY 1957

Figure 9

then northward, paralleling the Arch. This may be indicative of an erosional feature and may be partly the result of a downwarp in conjunction with deposition, as suggested by the Banff isopachs. The marked erosional thinning over the north portion of the Arch is possibly the result of slight uplift. The thick trend extending across the Arch in the south part of the area, on the other hand, would appear to preclude arching or uplift in that area during Mississippian time or during the post-Mississippian erosional period. It should be mentioned that regional isopachs do show an area of Mississippian thinning in Western Saskatchewan, separating the Williston basin from the geosynclinal area. Only the west flank of this feature is evident in Figure 9.

JURASSIC

Jurassic sediments overlie the Mississippian except for the northern portion of the area where the Mississippian is directly overlain by the Cretaceous. Thus, a major hiatus exists at the top of the Mississippian, covering the Pennsylvanian, Permian and Triassic periods. There was probably no appreciable deposition in the area during this time.

Isopachs of the Jurassic (Figure 10) show regional thinning coincident with the Sweetgrass Arch, suggesting the area was high relative to the adjacent Williston and Alberta basins. This thinning is apparently both depositional and erosional and would appear to be the result of activity related to the Sweetgrass Arch. Jurassic sedimentation varies considerably from one side of the Arch to the other. The predominantly shale section of the Fernie formation lies to the west, while to the east are shales, sandstones and limestones typical of the Williston basin section. The section over the Arch area consists of sands and shales apparently akin to the section of the Williston basin.

LOWER CRETACEOUS

The Lower Cretaceous in the Sweetgrass Arch area comprises the "plains Blairmore" formation, the Bow Island sand series and the shale interval between the Bow Island and Fish Scale Sand. Lower Cretaceous sediments consist of sands, silts and shales and are believed to have been derived from Nevadan orogenic uplifts to the west. The section is chiefly continental although it grades to marine northeastward and upward in section.

Isopachs of the Lower Cretaceous (Figure 11) show a northeastward thinning, with a broad anomalous belt straddling and paralleling the Jurassic pinchout. A belt of relatively thin sediments lies along the erosional edge of the Jurassic with a belt of relatively thick sediments to the northeast, beyond the limits of the Jurassic. A Mississippian topographic escarpment apparently caused this anomalous trend. Another area of thinning is noted in the northeast part of the map-area, again straddling the Jurassic pinchout. This is probably also related to a Mississippian erosional feature. Definite thinning is lacking over the Sweetgrass Arch, but a somewhat anomalous trend is coincident with it, lying at right angles to and seemingly barring the aforementioned Mississippian escarpment. This might represent slight activity relative to the Sweetgrass Arch.

UPPER CRETACEOUS

Isopachs of the marine shale interval from the top of the Colorado group to the "Base of Fish Scale" marker (Figure 12) show a strong eastward thinning in the western portion of the map-area, changing to northeastward thinning in the east. This is complimented by a broadening of the isopach spacing over the Sweetgrass Arch area. The appearance of anomalous thinning south of the border suggests this broadening is related to slight positive action of the Sweetgrass Arch.

The partial erosion of the overlying Milk River, Belly River, Bearpaw and St. Mary River formations in the Sweetgrass Arch area prevents further assessment of the depositional history through isopachs. About all that can be said is that there is no apparent evidence in the pre-

SOUTHERN ALBERTA
ISOPACHS
JURASSIC

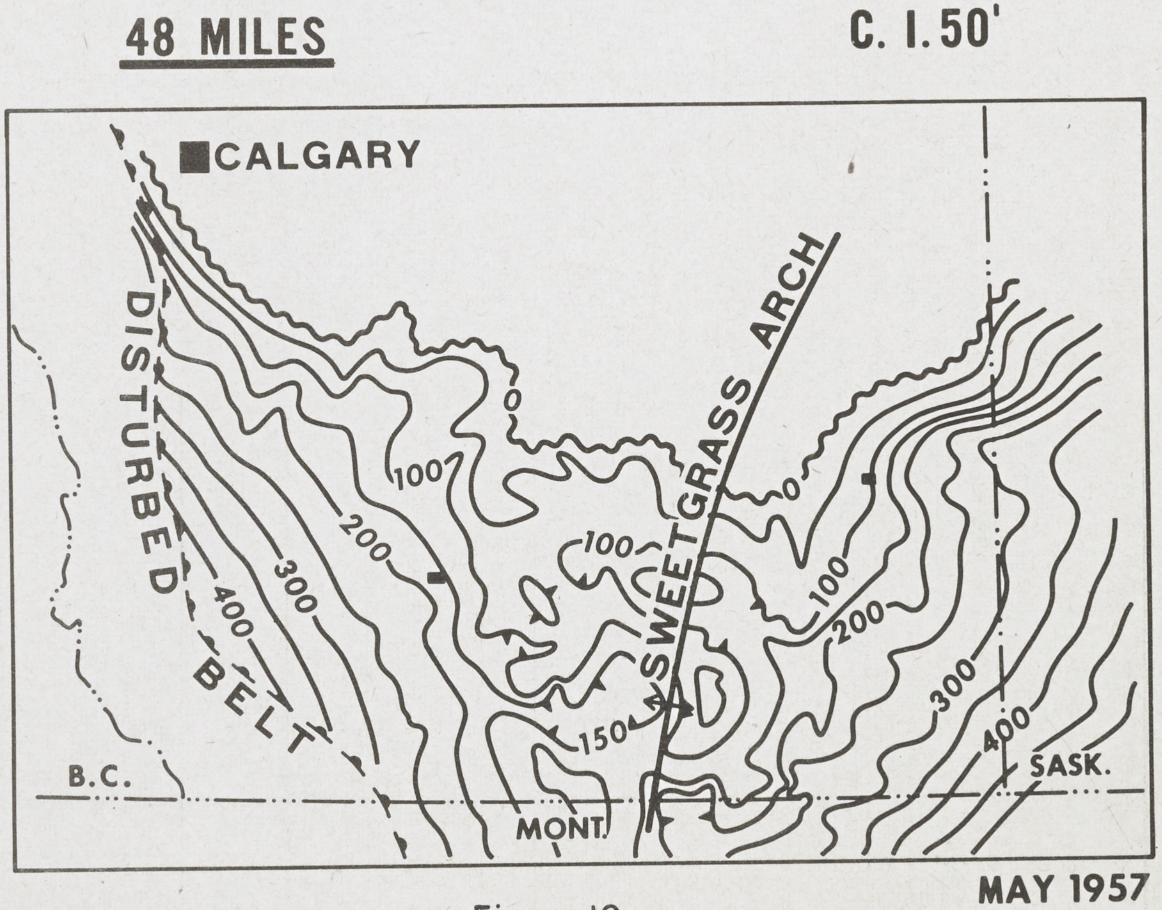


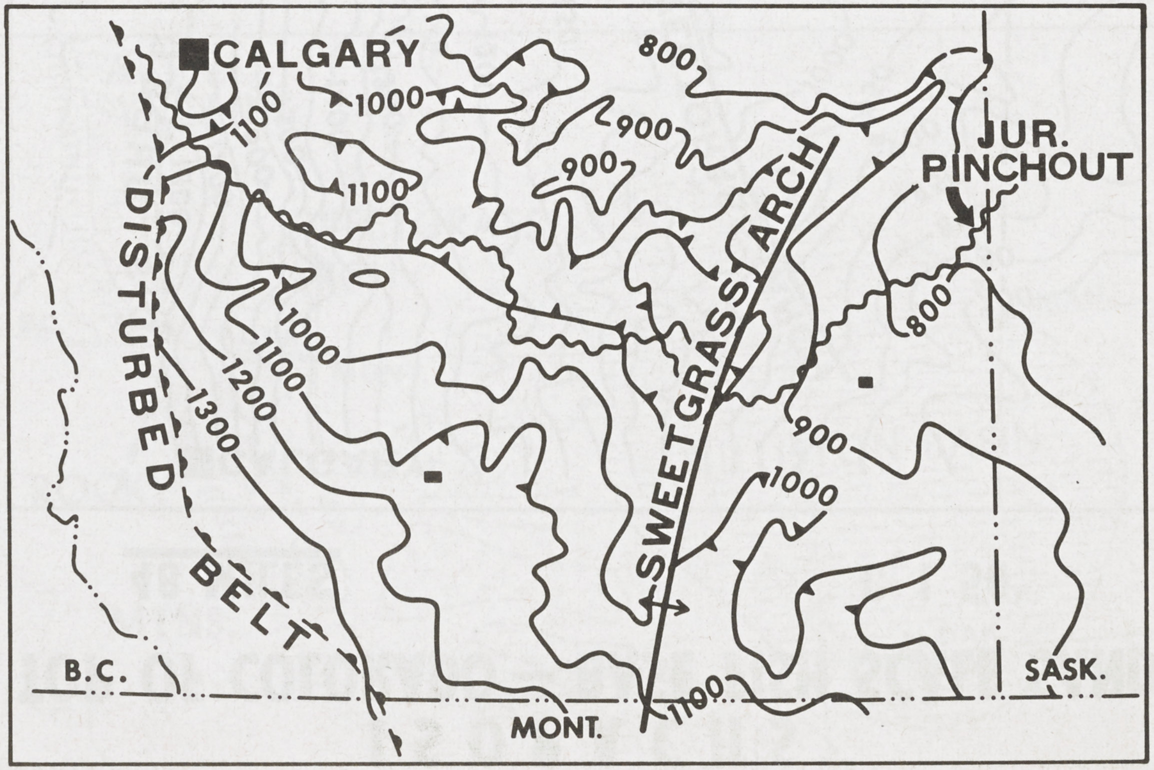
Figure 10

SOUTHERN ALBERTA

ISOPACHS
LOWER CRETACEOUS

48 MILES

C. I. 100'



MAY 1957

Figure 11

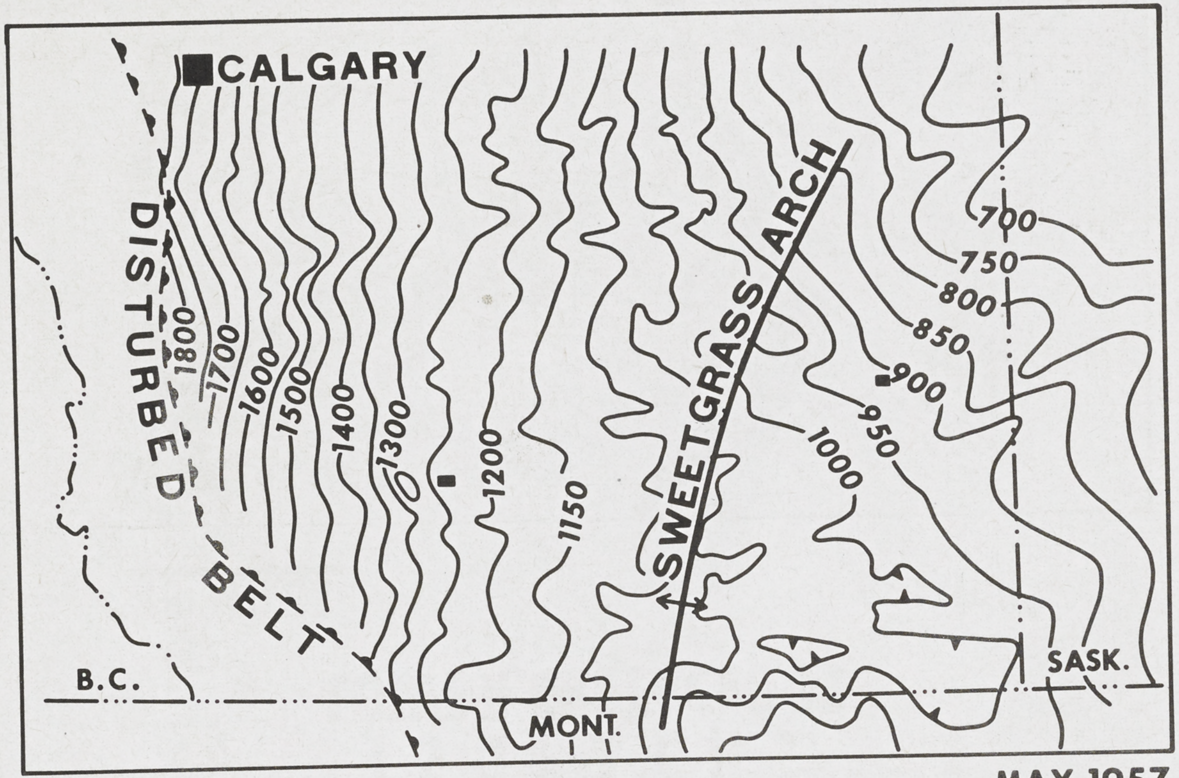
SOUTHERN ALBERTA

ISOPACHS

TOP OF COLORADO — BASE FISH SCALE SAND

48 MILES

C. I. 50'



MAY 1957

Figure 12

REGIONAL STRUCTURE

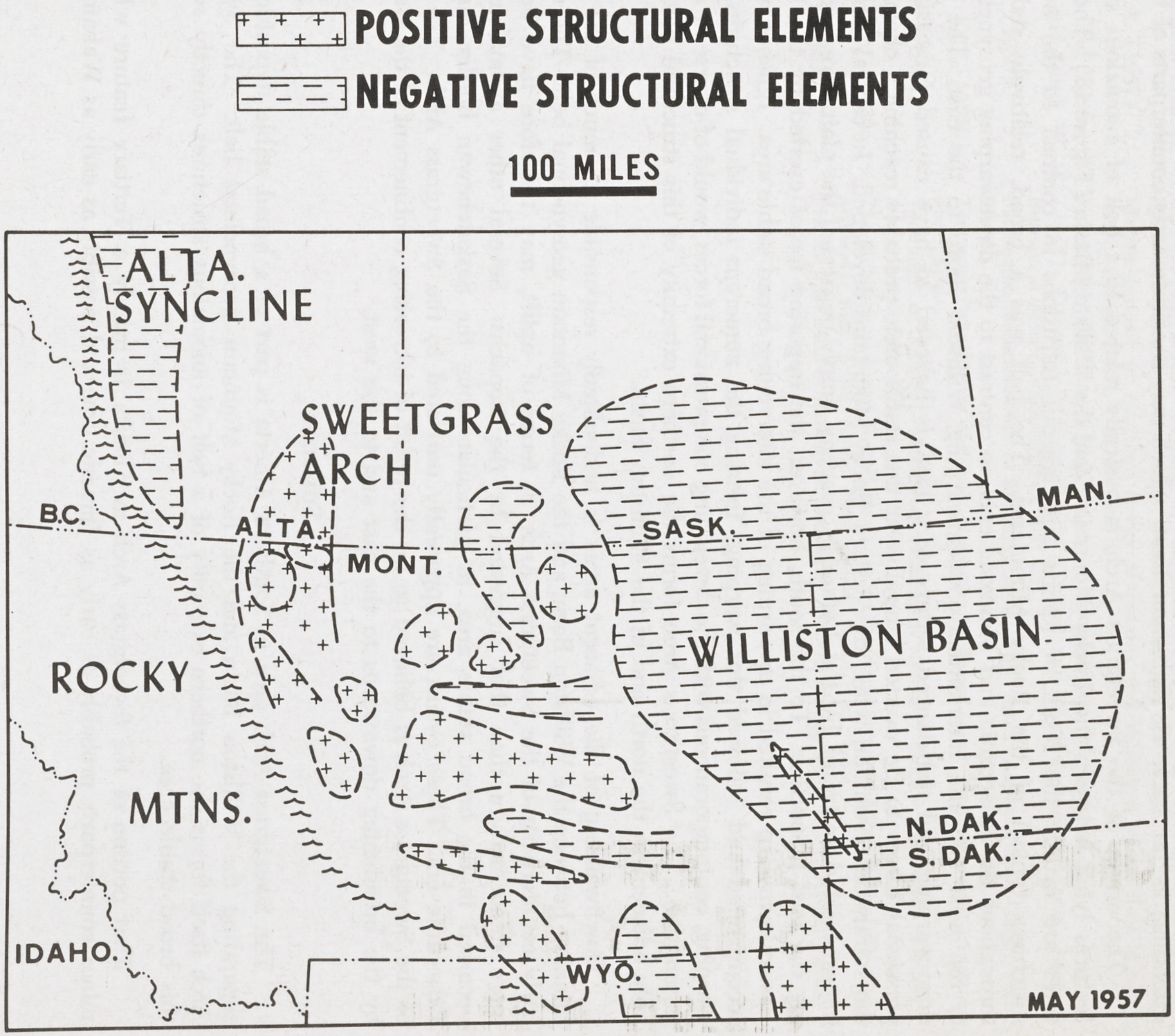


Figure 13

served sediments to indicate any appreciable activity related to the Sweetgrass Arch during this time.

AGE AND ORIGIN OF THE SWEETGRASS ARCH

The foregoing isopach maps suggest that, although mainly a Tertiary feature, there was slight activation of the Sweetgrass Arch in its present form during Jurassic time and very slight activation in Colorado time. In addition, several other minor anomalous events occurred, extending as far back as Wabamun time, which may consitute early counterparts of the Arch.

The origin of the Sweetgrass Arch is basically related to a belt of anomalous structural features lying between the Rocky Mountains and the Williston Basin (Figure 13). These structures are mainly the result of uplifts and igneous intrusions in contrast to the overthrust structures typical of the Rocky Mountains. The belt was a broad, relatively stable area throughout the Palaeozoic and Mesozoic eras, in contrast to the downwarping geosynclinal belt to the west and the intermittently downwarping Williston Basin to the east. The adjacent downwarping and unbalanced sedimentary load is believed to have caused increasing compressional forces to be exerted laterally on this stable area, probably reaching a climax during the Laramide revolution when the eastern Rocky Mountains developed. In central Alberta, the forces exerted eastward by the Laramide orogeny simply depressed the plains area, accentuating the vast monocline. To the south, however, the opposing forces exerted by the Williston Basin downwarp resulted in upwarping of the intervening broad stable area. Igneous intrusions accompanied and followed this warping, forming the numerous individual structures. Minor warping, contemporaneous with the developing compressional forces, would of course be a natural assumption. The Sweetgrass Arch forms the northern extremity of this structural belt, noticeably adjacent to the north end of the Williston Basin.

Downwarping of the adjacent areas is undoubtedly responsible for much of the regional thinning between the Williston Basin and the Rocky Mountain geosynclinal belt. The apparent early counterparts of the Sweetgrass Arch, in terms of uplift, may therefore have been of a more minor nature than that suggested by the isopachs. Several other anomalous events occurred in the broad stable area, in particular along the Saskatchewan border during the Palaeozoic era. These events are apparently unrelated to the Sweetgrass Arch. The location of the Sweetgrass Arch is believed to be the result of increasing confinement of the stable area by the broadening downwarps to the east and to the west.

SUMMARY

The Sweetgrass Arch area in Southern Alberta is part of a broad stable depositional area separating the Wililston Basin and the Rocky Mountain geosynclinal belt. The Sweetgrass Arch itself forms the northern extremity of a belt of anomalous structures directly related to this broad stable area.

That portion of the Sweetgrass Arch in Alberta is mainly a Tertiary feature which had minor counterparts probably as early as Jurassic time and possibly as early as Wabamun time.

BIBLIOGRAPHY

Alpha, A. G. (1955): Tectonic History of North Central Montana; Billings Geo. Soc., Sixth Annual Field Conference, pp. 129-143.

Andrichuk, J. M. (1951): Regional Stratigraphic Analysis of Devonian System in Wyoming, Montana, Southern Saskatchewan and Alberta; Bull. Amer. Assoc. Petrol. Geol., Vol. 35, no. 11.

Baillie, A. D. (1955): Devonian System of Williston Basin; Bull. Amer. Assoc. Petrol. Geol., Vol. 39, no. 5.

Blackstone, D. L. (1956): Introduction to the Tectonics of the Rocky Mountains; Geological Record, Rocky Mountain Section - Amer. Assoc. Petrol. Geol., pp. 3-19.

Derry, D. R. et al (1950): Tectonic Map of Canada; Geol. Assoc. of Canada.

Eardley, A. J. (1951): Structural Geology of North America; Harpers Geoscience Series.

Francis, D. R. (1957): Jurassic Stratigraphy of Williston Basin Area; Bull. Amer. Assoc. Petrol. Geol., vol. 41, no. 3.

Longwell, G. R. et al (1944): Tectonic Map of the United States; Amer. Assoc. Petrol. Geol.

Mallory, W. W. (1956): Tectonic Development of the Cordilleran Region; Geological Record - Rocky Mountain Section, Amer. Assoc. Petrol. Geol., pp. 37-48.

Milner, R. L. and Thomas, G. E. (1954): Jurassic System in Saskatchewan; Western Canada Sedimentary Basin Symposium, Amer. Assoc. Petrol. Geol., pp. 250-267.

Peterson, J. A. (1957): Marine Jurassic of Northern Rocky Mountains and Williston Basin; Bull. Amer. Assoc. Petrol. Geol., Vol. 41, no. 3.

Russel, L. S. and Landes, R. W. (1940): Geology of the Southern Alberta Plains; G.S.C., Mem. 221.

Sloss, L. L. and Laird, W. M. (1946): Devonian Stratigraphy of Central and Northwestern Montana; Mont. Bureau of Mines, Preliminary Chart 25.

Sloss, L. L. (1950): Palaeozoic Sedimentation in Montana Area; Bull. Amer. Assoc. Petrol. Geol., Vol. 34, no. 3.

Sonnenberg, F. P. (1956): Tectonic Patterns of Central Montana; Billings Geol. Soc., Seventh Annual Field Trip.

Staggs, J. O. (1956): Tectonics of Central Montana; Geological Record, Rocky Mountain Section, Amer. Assoc. Petrol. Geol., pp. 29-36.

Thom, W. T., Jr. (1923): The Relation of Deep-Seated Faults to the Surface Structural Features of Central Montana; Bull. Amer. Assoc. Petrol. Geol., vol. 7, pp. 1-13.

Weir, J. D. (1949): Marine Jurassic Formations of Southern Alberta Plains; Bull. Amer. Assoc. Petrol. Geol., Vol. 33, no. 4.

RELATIONSHIP OF THE PORCUPINE HILLS TO EARLY LARAMIDE MOVEMENTS

D. O. BOSSORT [1]

The Porcupine Hills extend as a topographic feature paralleling the Foothills from Township 6, to Township 17, in southwestern Alberta. The hills are formed by erosion of the conglomerates, sandstones, and shales of the Porcupine Hills formation, within the confines of the Alberta Syncline. Beneath the Porcupine Hills formation lie the soft varicolored shales of the Willow Creek formation, which are in turn underlain by the sandstone and shale sequence of the St. Mary River formation. For detailed lithologic descriptions of these formations reference is made to Douglas (1950).

Tozer (1952 and 1953) has proposed the following ages for these formations: The Porcupine Hills formation is assigned a middle and upper Fort Union Age, of the early Paleocene Epoch; the uppermost unit of the Willow Creek formation is assigned a lower Fort Union Age; the remainder of the Willow Creek formation is assigned a Lance Age, of the late Cretaceous Period; the upper St. Mary River formation is assigned a Fox Hills Age and the lower St. Mary River formation a Pierre Age, both of the late Cretaceous Period.

Tozer (1952 and 1953) and Bell (1949) have discussed the lateral correlations and boundaries of the above formations and reviewed the earlier literature. In the area under consideration, specifically the western margin of the Porcupine Hills and the adjacent Foothills in the Cowley and Callum Creek Map Areas, all workers seem in agreement that sedimentation continued uninterrupted during the deposition of the St. Mary River and Willow Creek strata. In the Callum Creek Map Area and in the Langford Creek Map Area to the north, Douglas (1950) has described an unconformity between the Willow Creek formation and the overlying Porcupine Hills formation, which bevels progressively older units of the Willow Creek formation northward. Hage (1942) maps the Porcupine Hills - Willow Creek contact as conformable in the Cowley map area. Tozer (1953) finds "no evidence of a stratigraphic break" in exposures on the Castle and Waterton Rivers to the south.

The nature and age of the Porcupine Hills - Willow Creek contact is of prime importance in dating the beginnings of the Laramide movements in the area under consideration. Deep seated faulting in the foothills west of the Porcupine Hills - Willow Creek contact, (see cross section) has no surface expression east of the contact. This faulting can be traced with reflection seismograph eastward beneath the Porcupine Hills - Willow Creek contact. The throw of this faulting is believed sufficient to ensure its penetration to the surface at the time of its inception. Similar faulting may occur in the Gulf Baysel Cyr #10 well, Lsd. 10, Sec. 14, Twp. 6, Rge. 30, W4th Meridian, some 6 miles southeast of the Cowley Map Area. This well encountered a fault at a depth of approximately 9,000 feet, which has a stratigraphic throw of 1,150 feet. The well is located on the Willow Creek formation outcrop belt, west of the Porcupine Hills - Willow Creek contact. Such faulting has not been recognized in surface mapping east of the well location.

Surface traverses along the Oldman River and in the Porcupine Hills reveal deformation in the Willow Creek and all older strata, while folding and faulting are conspicuously absent in the Porcupine Hills strata. Bulk densities of outcrop samples of Porcupine Hills sandstones are significantly lower than those of samples from the older formations; whereas the values obtained from the St. Mary River and Belly River sandstones are quite similar. A compacting agent other than depth and duration of burial is inferred for the older samples.

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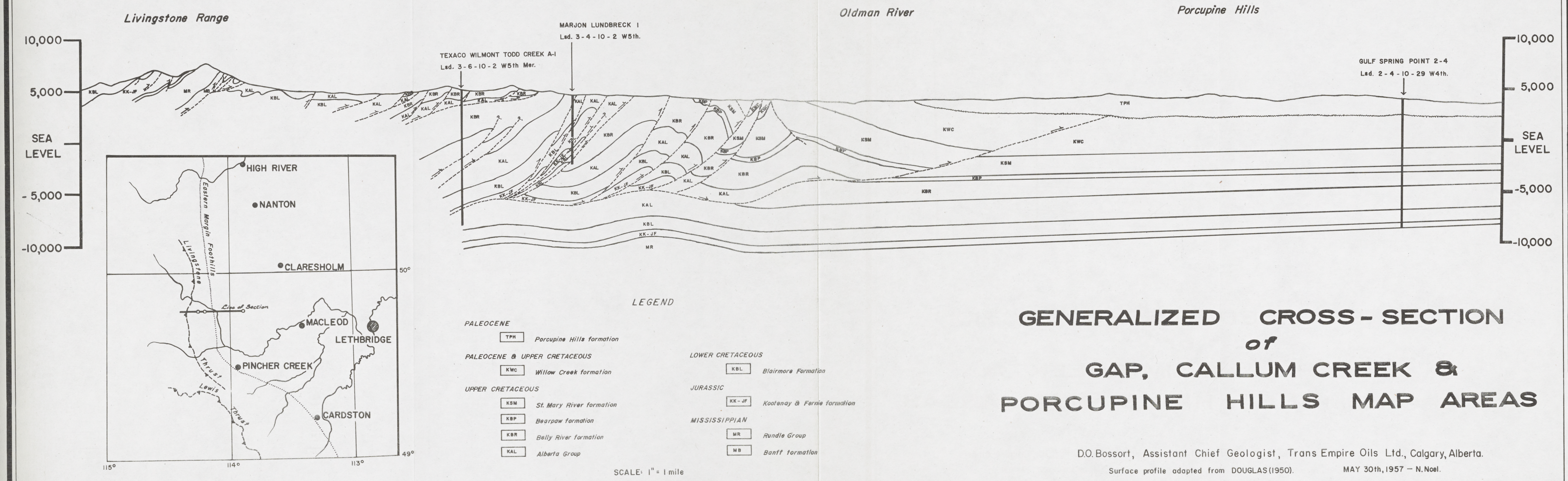

GENERALIZED CROSS-SECTION of GAP, CALLUM CREEK & PORCUPINE HILLS MAP AREAS

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Surface profile adapted from DOUGLAS (1950). MAY 30th, 1957 — N. Noel.

Conclusions

From the above observations the following is concluded:

(1) In the Area under consideration, the Porcupine Hills formation is separated form the underlying Willow Creek formation by an erosional unconformity of considerable magnitude.

(2) Laramide faulting, known in the subsurface west of the Porcupine Hills - Willow Creek contact, terminates at this unconformity.

(3) The Porcupine Hills strata were deposited after the beginning of the Laramide movements in this area; whereas the Willow Creek and all older sediments are pre-deformation.

(4) Using Tozer's Age determinations, a lower to lower middle Fort Union Age, of the early Paleocene Epoch, is postulated for the beginning of the Laramide Orogeny in the area under consideration.

The above conclusions are set forth, in an attempt to date the early Laramide movements in one segment of the Alberta Foothills. Regional application is not intended. On the contrary, the writer suspects the Laramide stresses may not have culminated in deformation at precisely the same time along the entirety of the Foothills belt.

BIBLIOGRAPHY

Bell, W.A. (1949): Uppermost Cretaceous and Paleocene Floras of Western Canada; Geol. Surv. Can., Bull. 30.

Douglas, R. J. W. (1950): Callum Creek, Langford Creek, and Gap Map Areas, Alberta; Geol. Surv. Can., Mem. 255.

Hage,C. O. (1942): Cowley Map Area; Geol. Surv. Can., Map 816A.

Tozer, E. T. (1952): The St. Mary River - Willow Creek Contact on Oldman River, Alberta; Geol. Surv. Can., Paper 52-3.

(1953): The Cretaceous - Tertiary Transition in Southwestern Alberta; A'ta. Soc. Pet. Geol., 3rd Ann. Field Conf. Guide Book.

SOME FEATURES OF THE SURFICIAL GEOLOGY OF THE FORT MACLEOD REGION OF ALBERTA [1]

A. MAC S. STALKER [2]

Introduction

The present paper deals with certain features of the surficial geology of that part of southwestern Alberta lying between 113 and 114 degrees longitude and 49 and 51 degrees latitude. It consists of a general discussion, in accordance with present knowledge, of the glacial section and the manner and limits of glaciation in the region. Emphasis is on the final glaciation, and those factors responsible for features that can be observed during the field trip. This region was studied by the author between 1953 and 1956 while he was engaged in routine mapping of surficial deposits.

General discussions of the Pleistocene and Recent geology of southern Alberta are found in the reports of Dawson (1885) and Dawson and McConnell (1895) on their early explorations, largely along the river and stream valleys of the region. There are also reports of Johnston and Wickenden (1931), Rutherford (1941), and Bretz (1943) on broad areas of southern and central Alberta and Saskatchewan. Horberg (1952) describes the general drift section along the Oldman River near Lethbridge and (1954) the glacial geology of a region near Waterton Park. Douglas (1950) describes the glacial geology of an area lying west of the fifth meridian (114 degrees longitude), which is just west of the present region, and discusses the inter-relation of the mountain and alpine glaciers with the Laurentide glaciers. Stalker (1953) gives some general information about major glacial features in southwestern Alberta.

The Surficial Section

The best sections through the drift of the region, and perhaps in all of Alberta, lie along the Oldman River between the fifth meridian and Taber, where it cuts the valley fill in its pre-glacial channel.

The most complete section known to the writer, though not by any means the thickest, is on the northwest bank of the Oldman River about 4 miles to the northeast of Brocket, in the general vicinity of Sec. 34, Twp. 7, Rge. 28, W.4th M. This section, obtained from observations made at several different points and using approximate thicknesses for the beds, which thicken and thin rapidly, is as follows:

General Section on the Northwest Bank of the Oldman River; Sec. 34, Twp. 7, Rge. 28, W.4th M.

Reference Letter	Thickness (feet)	Description
M	21	sand and silt, becoming stony towards the top; may include some outwash.
L	5	silt and clay, varved; varves average 3 inches in thickness.
K	10	sand, fine to medium; no stones.
J	10	silt and clay, varved; numerous stones near base, becoming rare toward top; varves average 3½ inches in thickness.
I	2	silt; numerous stones.
H	10	till, silty, light brown, moderately stony.
G	4	silt and fine sand; numerous stones; light brownish-grey.

(1) Published by permission of the Director, Geological Survey of Canada, Ottawa.
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F	10	till, dark brown becoming light brown toward top, weak and slumps readily; vertical jointings; contains a moderate number of stones from the Precambrian Shield.
D	12	till, dark brown to black; massive; contains number of stones from the Precambrian Shield.
C	9	till, light grey if dry, dark brown if damp; blocky to columnar joinitng; lacks stones from the Precambrian Shield.
B	4	gravel, pre-glacial (Saskatchewan Gravel); stones mostly 2 to 3 inches and a few to 10 inches in diameter.
A	5	bedrock; Willow Creek formation.
	–––	level of Oldman River.
	112	

The pre-glacial gravel (B) is equivalent to the "Saskatchewan Gravels and Sands" found near the bottom of most of the pre-glacial river valleys in southwestern Alberta, and are present locally as scattered deposits on high ground. Similar gravel can be seen lying directly above bedrock and beneath the till along the Oldman Valley. ,where it is crossed by Highway Number 3 just west of Lethbridge. It is also similar to the gravels occurring near the tops of the Hand and Cypress Hills of the western plains. It is a river gravel, consisting of well-rounded, non-striated stones, apparently brought eastward from the mountains by the pre-glacial Oldman River. About 50 per cent of it consists of limestone and dolomite stones, 33 per cent sandstone and quartzite, and about 3 per cent of what appears to be stones from the Crowsnest Volcanics, all from a mountain source. The rest consists of fragments of local bedrock. Stones from the Precambrian Shield have not been found in it. This gravel commonly grades into the overlying till. There is an increasing amount of the matrix sand, silt, and clay toward the top until the material is a typical till. A similar graditional contact between pre-glacial gravel and overlying till is present in the Elbow Valley near its junction with the Bow Valley in the eastern part of Calgary.

The lowest till (C) evidently represents a Cordilleran valley glacier that flowed down the Oldman Valley and is the stoniest of the tills in the section. This, along with the fact that the relative proportions of limestone, dolomite, mountain sandstone, quartzite ,and Crowsnest Volcanics are practically the same as in the pre-glacial gravel, suggests a high content of this gravel in the till. However, the proportion of local bedrock fragments has increased from about 10 to around 25 per cent. The apparent lack of stones from the Shield suggests that the glacier that deposited this drift was not preceded by any Laurentide glaciers, but would probably represent the first glacier into the region. This is a hard, resistant till with columnar jointing, which forms near vertical cliffs along the river. Pebble orientation study in this till indicates a direction of ice movement of north 41 degrees east (or south 41 degrees west), or almost parallel with the Oldman Valley in the district.

A well-developed boulder pavement separates the bottom till from the second lowest (D). The upper surfaces of the boulders in the pavement are planed off and strongly striated, the average strike of the striae, being north 40 degrees east. Pebble orientations in the overlying till ,however, indicate an ice movement from north 51 degrees east (or south 51 degrees west). This is generally a massive, black or dark brown till, which is very sticky when wet. It is somewhat less resistant than the underlying till, and does not form as near-vertical cliffs. About 10 per cent of the stones in this till came from the Shield, which is the lowest occurrence of such stones in this section. Otherwise its stone content is similar to that of the underlying till (C). In those parts of southwestern and central Alberta which are too far to the east to have been reached by valley glaciers, it is till (D) which normally overlies the pre-glacial gravels, or lies directly on bedrock in the pre-glacial valleys. In this section, it is separated from the overlying till by a sharp, horizontal contact, which is rusty from seepage of groundwater.

The overlying till (E) is bluish in colour and has the strong columnar jointing that forms the spectacular till bluffs present along some of the river valleys in southern Alberta (e.g. along

the Oldman River near Lethbridge). It is a sticky, hard till. There is a marked decrease in Shield stones as compared with the underlying till (D) and these represent only 1 or 2 per cent of the pebbles. All the Shield stones in it may have come from the underlying till, rather than directly from the Shield. Pebble orientations indicate the ice movement which deposited this till had a direction of north 58 degrees east (or south 58 degrees west).

The next till upward (F) is light to dark brown. It is silty with rusty streaks and is massive or has vertical jointing. It is weaker than the underlying till (E) and forms less steeply inclined cliffs. The contact between these two tills here appears to be gradational, and the upper till may represent a coarser and less plastic part of the underlying till. Pebble orientations indicate the same direction as in the underlying till of north 58 degrees east (or south 58 degrees west), for the movement of the glacier that deposited it. However, for various reasons, some of which will appear below, the writer considers that there is a strong likelihood that this till represents a separate ice advance. An increase of Precambrian Shield stones to about 8 per cent may indicate that the upper till (F) was formed by ice that had come from a more northeasterly direction or from farther than the one that deposited the lower till; or it may just represent a concentration of Shield stones due to some local factor. This till has a sharp contact with the overlying silt and sand.

The silt and sand (G) that underlies the top till (H) locally contains varved silt and clay. It may have received much outwash from the approaching glacier, as it becomes stonier towards the top, and the bedding becomes poorer. Its contact with the overlying till, where observed, is generally gradational. However, there does occur locally, what may be traces of another dark blue till underlying the top till (H). If these traces do represent another till, the last glacier appears to have destroyed most of it. The remainder of the section ,and perhaps this silt and sand also, appears to be associated with the last glaciation.

In this area, the glacier that deposited the top till (H) advanced into pro-glacial lakes that were present at its margin and was followed closely by such lakes during its retreat. This was a result of its having advanced up a valley that carried water from the west, and during its retreat and melting, having blocked the present Oldman River. The till itself is silty, stony, and is light brown in colour. About 4 per cent of the stones in it are of Shield types, and Crowsnest Volcanics constitute only about 1 per cent which is the lowest proportion of these in any of the tills. The direction of ice movement indicated from pebble study is north 44 degrees east (or south 44 degrees west). This is the weakest till of the five, and cuts in it usually slope gently and are quickly overgrown. There is much slumping, both in it and along the weak, unconsolidated, underlying silt. In addition, the overlying sand and silt commonly flows over and obscures the surface of the till. As a result, this till (H) is not as prominent along the Oldman Valley as some of the older ones and its rather gently sloping surface towards the top of the valley wall is commonly hidden by grass cover. It is therefore, easy to assume in many places that the underlying till (F) is the surface one. Till (H) is, however, the common surface till in most of the region, with the exception of the high ground (generally above 4,500 feet altitude?) to which this glacier did not reach, and those areas over-run by late Cordilleran ice. The siltiness of this till (H) is partly a local phenomenon, due both to the overriding of the pro-glacial lake deposits by the glacier and the removal of fine material by meltwater. Elsewhere, away from the Oldman Valley, the till contains more clay, but it is generally siltier than the underlying tills (C, D, and E). It is nowhere as hard and resistant as these other tills, and it everywhere retains its brownish or yellowish colour.

The contact between the top till and the overlying stony silt (I) is in places gradational. This silt was laid down immediately upon local retreat of the ice, and it probably consists largely of outwash from the glacier. It corresponds to the coarse, silt layer of the first varve, and the typical varved silt and clay (J) starts with the first dark clay band. Most of the clay

bands are ½ inch thick, and the silt bands about 3 to 3½ inches thick. Stones are rare towards the top of this silt and clay, due in part to the distance from the ice margin becoming greater during deposition, but mostly as a result of an increasing proportion of the material being brought into the pro-glacial lake by the Oldman River from the west. For this reason, few stones were ice-rafted in. The contact with the overlying fine or medium sand (K) was not seen.

The increased coarseness of material represented by the overlying sand (K) probably represents a change in river or lake currents from those prevalent during deposition of the varved silt and clay, rather than a glacier readvance. This may have been caused by a decrease in size of the lake resulting in coarse material being brought nearer the ice front. The sand is nearly stoneless, whereas, if it did represent g'acier readvance, there should be more ice-rafted stones present. Sand (K) grades upwards into varved silt and clay (L), which is probably a continuation of the lower varves, whose deposition was interrupted by the change of currents that caused deposition of the sand. These varves are similar to the lower ones, but are somewhat contorted towards the top, perhaps during periglacial conditions; slumping during deposition; or by pressures caused by a small glacier readvance near their location.

The varved silt and clay grades into the overlying deposits (M) which vary greatly within short distances. They start here with about 7 feet of stoneless silt and sand, which probably represents a change in currents in the lake or river. The sand is overlain by some 8 feet of sand which, in turn, is overlain by some 6 feet of very stony sand which contains boulders up to 2 feet in length. The latter sand is near the surface and is much weathered. It is thought to be largely outwash, particularly since the large quartzite erratics (mentioned later) are found scattered over its surface. The ice front was probably never very far away during deposition of the top 21 feet of material. A local readvance approaching this spot may have taken place and caused deposition of the outwash. However, readvance of the glacier was not absolutely necessary. As the lake drained, changing currents (with those carrying meltwater from the ice becoming relatively stronger) would have been sufficient to deposit the outwash. In addition, if the ice was 'dead' during its melting from this part of the Oldman Valley, as appears likely, such a local readvance would have been practically impossible.

The writer believes that most, or all of the glaciers that reached this part of the western prairies, except perhaps some of the younger Cordilleran Valley glaciers and some of the Wisconsin substadial glaciers, are represented in this section. He has not seen tills elsewhere in the region that cannot be fitted into it. It should be noted, however, that the directions of ice movement indicated in this section are only the local directions and do not necessarily correspond to the general directions. Indeed they are very unlikely to do so, as the movements of all the glaciers in this region were affected by the strike of the Oldman Valley, with which they agree roughly; also the Laurentide glaciers were flowing into the broad lowland south of the Porcupine Hills, which gave a westerly component to their movements.

Of the five tills present in the above section, the lowest is Cordilleran, and the others are classified as Laurentide. The top till (H) is the surface till of the region, and the other three Laurentide tills occur locally elsewhere in southwestern and central Alberta, particularly where protected from erosion in pre-glacial valleys. The four Laurentide tills retain everywhere much the same characteristics (particularly colour, jointing, and hardness) as described in this section. It is suggested that these basic features stem largely from the direction of movement of the various glaciers; thus the browner and coarser tills represent glaciers that moved southerly over the brownish Tertiary sandstones and siltstones, with addition of much material brought by valley glaciers from the west. The dark blue and black tills, on the other hand, would represent glaciers that moved southwestward over the dark bentonitic carbonaceous clay and silt beds of the Cretaceous formations of the plains. This is the simplest explanation of the dif-

ferences between the tills. Thus the brownish top till represents southeasterly movement in the general region. This is also indicated by the various ice-flow markings, such as drumlinoid ridges (Stalker and Craig, 1956) and by scattered pebble orientation studies farther to the east. In addition, the low percentage of Shield type stones in the top till, as compared with the lower tills, also indicates such a movement.

The lowest of the four Laurentide tills (D) is recognized elsewhere by its distinctive blocky jointing, blackish colour, and heavy sticky character. The writer had confused the middle two tills (E and F) in their occurrences elsewhere. However, they can generally be distinguished once the differences between them are known, by the darker colour of the upper till; its lack of columnar jointing; its lesser strength and stronger tendency to slump; and the formation of more gently-sloping cliffs. These two tills rarely occur together. If they had been implanted by the same glacier, the upper one of them should have protected the lower from erosion and where the upper one occurs, the lower should also be present. As the upper one apparently occurs by itself in several instances, it appears that these tills represent two separate ice advances.

Correlation

The various tills cannot be directly correlated with the standard North American Pleistocene section. One inter-till band, which apparently represents a major inter-glacial stage, occurs locally along the Oldman River from west of Lethbridge to east of Taber. This band has a radiocarbon date of more than 28,000 years (sample from Sec. 26, Twp. 9, Rge. 23, W.4th M.), and it appears that anything below it is Pre-Wisconsin. This band likely lies between the second and third (D and E) of the four Laurentide tills. At the chief point where it has been studied (Sec. 18, Twp. 9, Rge. 22, W.4th M., a few miles west of Lethbridge) two tills, apparently the silty top one and the weak, dark one (E) overlie it. However, if there are traces of dark till below the top till (H) as mentioned above, the band may lie between the third till (E) and the till represented by these traces. In this case, the inter-till band would correspond to the sand between the third and fourth Laurentide tills (E and H) in the section described above. The top till is undoubtedly of Wisconsin age. The Cordilleran till (C) and the lowest (D) of the Laurentide tills represent the first glaciation of the region, and as they directly overlie pre-glacial gravel, they may be of Nebraskan a ge. The next till (E) is apparently also of pre-Wisconsin age, and may be Kansan or Illinoian.

Upper Limits of Laurentide Glaciation

The writer has found Shield type stones at altitudes up to 5,500 feet in the Porcupine Hills, where they are fairly common in places. The strongest Laurentide glacier thus reached this height, and its surface probably was at an altitude between 5,500 and 6,000 feet. This glacier evidently was one of the first two Laurentide glaciers into the region (Horberg, 1952; p. 318) and most likely the first one, as it had a high content of Shield type stones. On the other hand, the surface of the last glacier (H) probably reached above 4,500 feet only locally. The writer has noticed that Shield type stones apparently increase above this approximate height, where the area has not been overrun by late Cordilleran ice. It would therefore, appear that below this altitude their concentration had been diluted by other stones brought in by the last glacier. Many small moraines lie in valleys in the Porcupine Hills around this altitude, and these may mark roughly the limit of the last Laurentide glacier.

Wisconsin Glaciation

The general movement of the last Laurentide glacier in the region was southeastward, and approximately parallel to the eastern edge of the Foothills (Stalker and Craig ,1956).

PLATE 1

Part of the quartzite erratic train. Note circular depressions around the blocks. Northwest of Claresholm, Alberta.

Sec. 9, Twp. 14, Rge. 28, W.4th M.

PLATE 2

Moraine plateaux (high flat areas) about 40 feet high in hummocky moraine. West of Big Valley, Alberta.
Sec. 30, Twp. 35, Rge. 20, W.4th M.

Locally, its movement was strongly affected by topography. The direction of flow changed rapidly to adapt itself to the large hills and broad lowlands, and to replace wastage taking place at the ice margin. Though the general flow was southeastward, the ice margin steadily moved westward as the ice thickened and was able to overrun continually higher ground. The region was enclosed on the west by the Foothills and Rocky Mountains, and on the south by the high ground of the Milk River Ridge. This was the major reason the ice tended to flow southeastward and around the Milk River Ridge to lower and warmer land in the United States, where wastage through melting was stronger.

North of Calgary, the western part of this Laurentide glacier appears to have received much Cordilleran ice from valley glaciers. South of Calgary, however, this glacier did not have much contact with Cordilleran ice except near Waterton, because high ground, such as the Porcupine Hills, effectively separated the Cordilleran and Laurentide glacier near their potential contact. Near Waterton, valley glaciers appear to have met the Laurentide ice-sheet for a short time in the Twin Butte-Mountain View district. A piedmont glacier formed by these valley glaciers may be responsible for much of the hummocky moraine in this district. The glacier in the Waterton Valley was the strongest of the valley glaciers, and it formed numerous drumlins, drumlinoid ridges ,and small moraines in front of the mountains. These can be seen for several miles along both Highways 5 and 6 near their junction in Waterton Lakes Park. Numerous cirques, hanging valleys, and a few U-shaped valleys in the mountains reflect the effects of the alpine glaciation.

One remarkable result of the last Laurentide glacier was a long erratic train composed of numerous quartzite blocks (Plate 1). It stretches from west of Edmonton south to the International Boundary at Coutts, and includes the largest known erratic in North America, the well-known 'Big Rock' some 6 miles west of Okotoks. Some excellent sections of this train are present in the area. For example, approximately 9 miles west of Fort Macleod; also between a point approximately 10 miles south of Fort Macleod and a few miles northeast of Glenwoodville. It is crossed by highways about 6 miles northeast of Brocket; about 8 miles north of Cardston; and near Raley. The train is generally ½ to 3 miles wide, being narrowest on steep slopes, but it widens greatly in the Peigan Indian Reserve. In the region it includes many blocks longer than 15 feet. The erratics, which were carried on the surface of the glacier and grounded during its melting, indicate the general movement of the western part of the glacier.

Wisconsin Deglaciation

The region was deglaciated through surface downmelting of the ice; through wastage and retreat at the ice margin; and through downdraw to low ground farther to the southeast, in the United States, where wastage was rapid. As the ice-sheet was bounded in the region by higher ground on the west and south, a slight marginal retreat by itself would cause a large increase in the surface slope of the ice near its margin. Marginal retreat would then of necessity cease until the surface of the ice-sheet had lowered enough to counteract this increased slope. Marginal retreat was therefore slow, although marginal wastage may have been large. The ice disappeared largely through surface lowering, especially through melting down in place. The downdraw of ice to the southeast may have been important enough to have caused the southeastward trend of many of the ice-flow markings.

Due to the large amount of surface lowering necessary before large scale marginal retreat took place, the various substages of the Wisconsin stage need not have caused much change in position of the ice margin. The same surface lowering that would cause marginal retreat of several hundred miles in flatter country farther to the southeast might here be represented by a margin retreat of only a few miles. Thus it is best to consider the Wisconsin glacier as a whole in this region, rather than trying to separate the various substages.

Stagnation of the ice-sheet was of major importance during the last deglaciation. In general, this feature was not sufficiently recognized in early discussions of the glacial geology of the western plains. The major cause of this widespread stagnation was that the ice did not have anywhere to flow, being shut in on the west and south by high land, and on the east and north by the main mass of the glacier. As the surface lowered 'dead' ice formed in a broad belt along the glacier margin and over any high land within the confines of the ice-sheet itself. Much of the region was thus covered with dead ice at one time or another during deglaciation and as a result, there are abundant 'dead ice forms' present. These include the hummocky moraines, the moraine plateaux, and the moraine, rim, and terrace ridges that are well described by Hoppe (1952). On the ground moraine plains they include the till-cored or solid till esker ridges (Madsen, 1900; pp. 103-109), several small representatives of which are present in this region (e.g. east of Highway 2 near Woodhouse), and what the writer designates 'plains plateaux' (till and silt mounds of Henderson, 1952; and the prairie mounds of Gravenor, 1955), which are forms similar to, though generally smaller than, the moraine plateaux, and which occur on ground moraine plains rather than in hummocky moraine. The term 'dead ice plateaux' can be used to include both types. The till-cored or all-till esker ridges are similar to normal gravel and sand esker ridges in every way except in composition. The moraine plateaux (Plates 2 and 3) (representatives of which are present in hummocky moraine some 10 to 15 miles south of Fort Macleod, and in the Lake McGregor Moraine about 35 miles east of High River), consist of flat-topped hills composed largely of water-deposited clay, silt, and sand. They commonly are bordered in whole or in part by till 'rim edges' (Hoppe, 1952; p. 5) ,which rise above the plateau surface proper. These plateaux may range up to 70 feet in height, but most are 20 to 40 feet high, and in diameter from a few hundred feet to several miles. The rim ridges may rise as much as 20 feet above the plateau surface, although generally only 5 to 15 feet. They dip towards the centre of the plateaux and under the central water-deposited sediments at low angles. Their outer sides dip steeply towards the bottoms of the depressions bordering the plateaux, and commonly approach the angle of repose for the material composing them. The plains plateaux are generally roundish in plan. Under ideal conditions where the centre of the plateau has been filled with water-deposited sediment, they tend toward a plateau form; otherwise, there is a central depression and the hill is formed only of the rim ridge and is doughnut shaped. These plains plateaux are 50 to 100 feet in diameter and 5 to 30 feet high, but most are about 300 feet in diameter and 15 feet high. Many of those in the present area are not completed and have half of the ring, generally the northern one, lacking. (Plate 4).

All these 'dead' ice forms have certain features in common. The till in them is generally of a basal type; tight, compact, and sticky, without much visible structure, and similar in every respect to the basal till in the nearby ground or hummocky moraine. With the exception of the till or till-cored esker ridges, pockets or lenses of water-deposited material within the till are rare, but most of the forms have water-deposited sediments associated with them. These occur either as centre fillings in the plateaux or as segments or pockets in the till of the esker or moraine ridges. In addition, depressions, such as troughs beside the esker ridges, or 'dead ice' hollows, or kettles beside the moraine ridges and moraine plateaux border many of the structures.

Similar dead ice forms could be built by various methods. However, considering the various features mentioned above, it appears that the method suggested by Hoppe (1952, p. 8) for his moraine ridges and rim ridges is suitable for, and gives the best explanation of the origin of all the present forms. This origin, which is intensively discussed by Hoppe, assumes that the till forming the rim ridges, moraine ridges, and till or till-cored esker ridges, was squeezed into holes, crevasses, or esker tunnels in the ice from beneath adjoining ice, through weight of the ice overlying it. This theory evidently assumes that much of the drift beneath the ice was not frozen during the late deglaciation. This method could give hills or ridges having a maximum height in the order of 75 feet. This agrees with what has been observed for any of the forms.

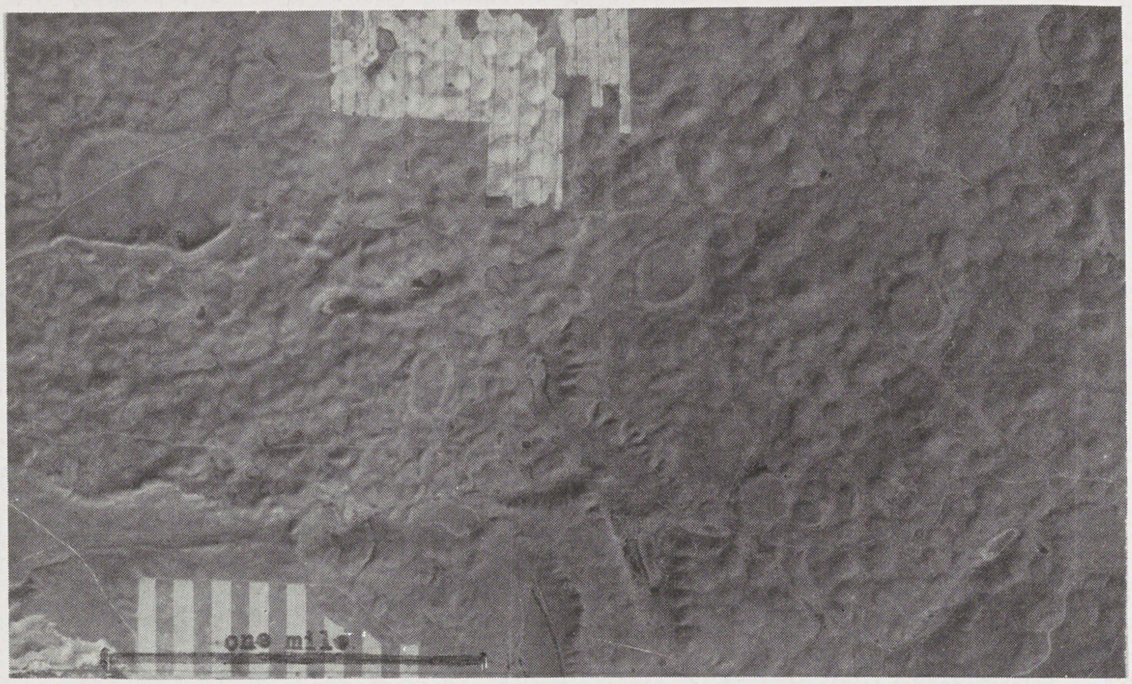

PLATE 3

Dead ice plateaux in low hummocky moraine. Note the rim ridges surrounding many of the plateaux. Seven miles east of Del Bonita, Alberta.

(Section of Royal Canadian Air Force vertical photograph A 15483-59).

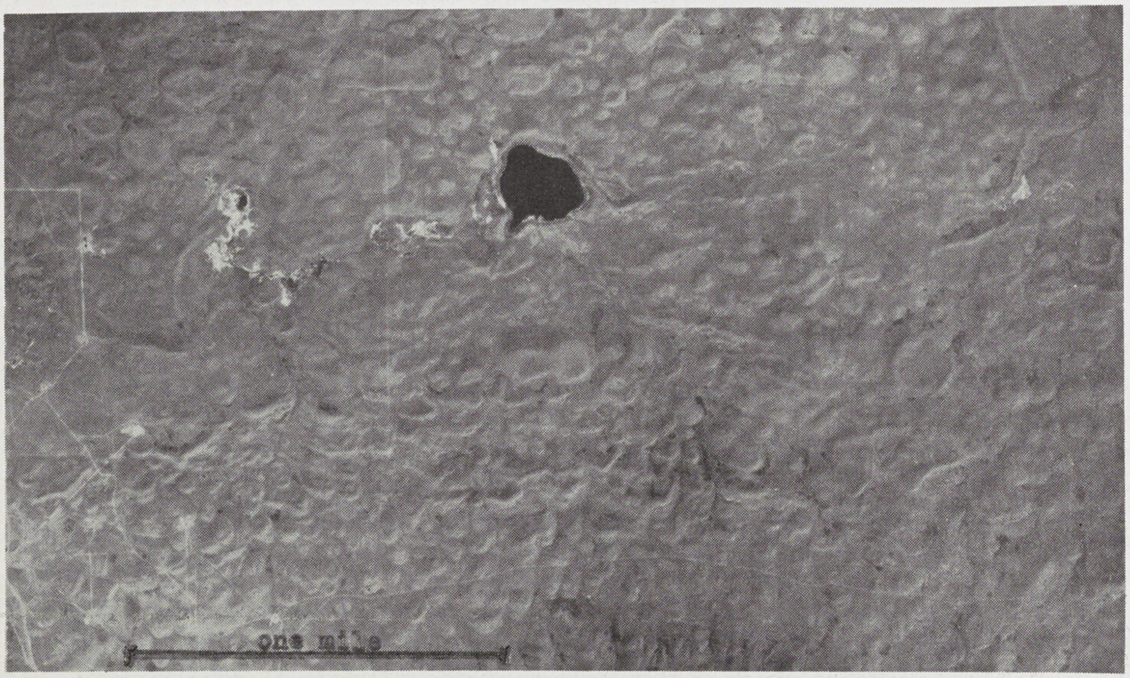

PLATE 4

Dead ice plateaux in low hummocky moraine or rolling ground moraine. Note rim ridges, and incomplete rings (northern half missing) in plains plateaux to the south.

(Section of Royal Canadian Air Force vertical photograph A 15483-63).

such an origin would also explain the presence of basal type till in the forms. The loss of till from beneath the adjoining ice would have caused, upon complete melting of the ice, the troughs and hollows that are present near many of the forms. Formation of the holes and tunnels near the base of the ice, necessary in this theory, is a major problem that cannot be discussed here. It can be seen on many present-day glaciers, that such holes do occur, and the presence of tunnels is shown by the numerous normal esker ridges found in many parts of formerly glaciated regions.

Some of the low plains plateaux could have formed through ice wedge growth in polygonal ground in permafrost areas, as suggested by Henderson (1952) and particularly the many that seem to have a hexagonal outline. However, such a method of formation is not suitable for the larger forms particularly the high moraine plateaux. Assuming sufficient material was present, in and on the ice within a short distance of the holes and crevasses, slumping of wet drift may have taken place. However, this seems unlikely for many of the larger forms as it would tend to give a coarser, ablation type till, commonly with more structure and gentler slopes, than is present in many of the moraine and rim ridges. This is particularly so if the holes and crevasses contained water, which appears likely. In this case, the clayey till would have slumped until the ridges had only gentle slopes, and the finer material would have been removed by the water, leaving a coarse, sandy or silty till. The common crevasse filling with its rather coarse material is an example of the result of this latter method of formation. In addition, meltwater streams would tend to form on the surface of the ice and deposit pockets of gravel and sand in the ridges. This would give irregular hills and widenings to the ridges, instead of the smooth, even ridges generally present. The common factor in all the various forms is their formation through squeezing or pressing of till into holes or crevasses from beneath adjoining ice. For this reason, the writer uses the expression 'ice-pressed forms' as an overall term for them. Some 'dead' ice plateaux can be seen from Highway No. 5, a mile northeast and 2 miles southwest of Spring Coulee; 2 to 4 miles east of Raley; just east of Mountain View; from Highway 6, 2 miles north of Twin Butte; and just south of High River on Highway 2.

The moraines of the region formed during the deglaciation are of the hummocky, knob and kettle type. They are formed of numerous small, roundish hills, with a few ridges, separated by irregular, undrained depressions. They are generally devoid of any particular lineation, and commonly contain many of the ice-pressed forms (particularly the moraine plateaux) described above. Most of this hummocky moraine is on high ground, generally bedrock highs (e.g. the moraine north of Okotoks near Highway 2, and on and to the east of the Peigan Indian Reserve). Striking features of much of this hummocky moraine are the lack of the outwash commonly associated with recessional moraines, and a general absence of large spillway channels (Johnston and Wickenden, 1931; p. 40). These various factors indicate that the moraines were built largely by ice that had stagnated over high ground, which was commonly back from the glacier margin.

In many instances, this stagnant ice was partly or totally enclosed by moving ice during formation of the moraines. The meltwater drained away beneath the surrounding ice, either by slow seepage ,or through channels that were, in many cases, later destroyed by the moving ice. Some of the valleys covered by hummocky moraine and which are commonly present near these large moraines, may represent these former sub-ice spillway channels.

These hummocky moraines should not be regarded as marking various successive ice margins during deglaciation. However, some may have been built on high ground during halts in the surface lowering of the ice-sheet, or during rejuvenations and thickenings of the glacier. Thus, though the moraines do not necessarily mark ice margins during the various Wisconsin substages, they may mark surface altitudes of the ice-sheet during these substages. True

recessional moraines, or moraines built along a glacier margin during a balance between melting and glacier advance, do occur locally, particularly along spillway valleys. Here the strong ice wastage caused by contact with running water induced ice flow toward the marginal rivers which acted to counter-balance the wastage. This brought much drift into these regions. Moraines formed in this manner occur between Nanton and High River, particularly near and to the west of Cayley on Highway 2.

Other Features

A remarkable series of ice-marginal valleys marked the western edge of the glacier during its retreat from the region. These are best represented in the Porcupine Hills, by the many dry coulees which reach a maximum depth of 700 feet and a width of about a mile (i.e. Canon Lake Valley west of Claresholm.) The valleys at high altitudes, especially in the Porcupine Hills, are generally short segments across ridges, and in the inter-ridge sections the rivers apparently flowed across ice. These rivers may have been superimposed on the ridges from the ice. The valleys on or near the plains are longer and more continuous. The one that is now used in part by Willow Creek, stretches for some 40 miles along the front of the Porcupine Hills.

These valleys carried not only meltwater from the ice, but also the drainage from the eastern slopes of the Rocky Mountains. These slopes, from Calgary south, were probably largely ice free at this time. A good example of a dry gap about 6 miles west of Nanton in the Porcupine Hills can be seen from Highway No. 2 near Nanton. This gap runs eastward and is more than 300 feet deep and approximately 5 miles long.

The ice-marginal lakes formed in the Porcupine Hills and Foothills were small and lay in the valleys, but on the flatter ground of the plains, large lakes were able to form. Glacial Lake Carmangay, some 20 miles east of Claresholm, was the largest in the region and covered some 350 square miles.

Between Fort Macleod and Brocket, Highway 3 crosses a series of outwash plains. Steep slopes on the east with a gentle slope westward, marks the ice boundary at the time the outwash to the west was deposited. The material consists mostly of sand and gravel near the former ice margins and sand and silt farther westward. Large boulders are scattered throughout.

The best dunes in the region are found between 5 and 12 miles northeast of Fort Macleod, and can be seen from Highway 3. These are the longitudional type dune, and trend east-northeastward (present-day prevailing winds in the region are from the west-southwest). These dunes reach a maximum height of about 50 feet, and may be more than two miles long. They are composed largely of fine sand or silt, whereas the smaller dunes a few miles east of Monarch are composed mostly of silt.

References

Bretz, J. Harlen (1943): Keewatin End Moraines in Alberta, Canada; Bull. Geol. Soc. Am., Vol. 54, pp. 31-32.

Dawson, G. M. (1885): Report on the Region in the Vicinity of the Bow and Belly Rivers, Northwest Territory; Geol. Surv., Canada, Rept. of Prog. 1882-3-4, pt. C.

Dawson, G. M., and McConnell, R. G. (1895): Glacial Deposits of Southwestern Alberta in the Vicinity of the Rocky Mountains; Bull. Geol. Soc. Am., Vol. 7, pp. 31-66.

Douglas, R. J. W. (1950): Callum Creek, Langford Creek and Gap Map-areas, Alberta; Geol. Surv., Canada, Mem. 255.

Gravenor, C. P. (1955): The Origin and Significance of Prairie Mounds; Am. Jour. Sci., Vol. 253, pp. 475-481.

Henderson, E. P. (1952): Pleistocene Geology of the Watino Quadrangle, Alberta; Indiana University, unpublished Ph.D. Thesis.

Hoppe, Gunnar (1952): Hummocky Moraine Regions with Special Reference to the Interior of Norbotten; Geografiska Annaler, Arg. 34, Hafte, 1-2, pp. 1-72.

Horberg, Leland (1952): Pleistocene Drift Sheets in the Lethbridge Region, Alberta, Canada; Jour. Geol., Vol. 60, No. 4, pp. 303-330.

(1954): Rocky Mountain and Continental Pleistocene Deposits in the Waterton Region, Alberta, Canada; Bull. Geol. Soc. Am., Vol. 65, pp. 1093-1150.

Johnson, W. A., and Wickenden, R. T. D. (1931): Moraines and Glacial Lakes in Southern Saskatchewan and Southern Alberta, Canada; Trans. Roy. Soc. Canada, Ser. 3, Sec. 4, Vol. 25, pp. 29-44.

Madsen, Victor (1900): Beskrivelse Till Geologisk Kort Over Danmark: Kortbladet Bogense; Danmarks Geologiska Undersogelse, 1, Raecke, Nr. 7.

Rutherford, R. L. (1941): Some Aspects of Glaciation in Central and Southwestern Alberta; Trans. Roy. Soc., Canada Ser. 3, Sec. 4, Vol. 35, pp. 115-124.

Stalker, A. M. (1953): Surficial Geology of Southwestern Alberta; Alberta Soc. of Pet. Geol. 3rd ann. Field Conference and Symposium, pp. 15-22.

Stalker, A. M., and Craig, B. C. (1956): Use of Indicators in the Determination of Ice-Movement Directions in Alberta, Canada: A Discussion; Bull. Geol. Soc. Am. Vol. 67, pp. 1101-1104.

FOSSIL VERTEBRATES OF SOUTHERN ALBERTA

By LORIS S. RUSSELL [1]

Introduction

By southern Alberta is meant here the area of the province lying south of Lethbridge and Medicine Hat. For the vertebrate palaeontologist this has no such rich treasures as are found in the badlands of the Red Deer River, farther north, but the extent and diversity of the Cretaceous section exposed in southern Alberta offers a variety of fossil occurrences not matched elsewhere in the province. This is the Bow and Belly River Region of Dawson (1884) and has been the scene of many geological investigations since his time. The purpose of the present remarks is to summarize the occurrences of fossil vertebrates within the area, giving the location, the geological situation, and something about the nature of the fossils themselves. Most of the information presented here is already in the literature, but scattered through a series of papers and reports. The discussion will be by geological formations, in order of antiquity.

Blairmore Formation

The present view is that no fossil vertebrates have as yet been recovered from the Blairmore formation of southern Alberta, or indeed from the Lower Cretaceous as a whole. Some years ago the complete foot skeleton of a small dinosaur was collected by Dr. C. H. Crickmay near Burmis. This was sent to the Museum of Geology of the University of British Columbia. Subsequently it was submitted to the late Mr. C. W. Gilmore, Curator of Fossil Reptiles in the United States National Museum. Mr. Gilmore (1924) described it under the name *Laosaurus minimus*, new species, *Laosaurus* being a genus of small, light-limbed herbivorous dinosaurs known previously only from the Upper Jurassic. Later stratigraphical studies in the Crowsnest Pass (Allan and Rutherford, 1932) indicated that the rocks in which this fossil had occurred were part of the Upper Cretaceous "Belly River" formation, and not the Blairmore. A restudy of the specimen (Russell, 1949) disclosed no special resemblances to *Laosaurus* or any other described ornithopod dinosaur, although some similarity was found in the English *Hypsilophodon* from the Wealden formation. Through the generosity of the University of British Columbia and the courtesy of Dr. M. Y. Williams, Curator of the Museum of Geology, the type specimen of "*Laosaurus*" *minimus* is now in the collection of the National Museum of Canada in Ottawa.

In spite of the negative findings so far, fossil vertebrates ought to occur in the Blairmore formation and also in the underlying Kootenay. Persons working in these formations should keep this possibility in mind.

Milk River Formation

The oldest formation exposed on the southern Alberta plains is the Alberta shale (Colorado shale of authors), an upper portion of which appears along the headwaters of Deer Creek, on the north side of the West Butte. One and a half exposures lie on the Canadian side of the International Boundary. No fossil vertebrates have been recorded from here, and in fact the Alberta shale and its equivalents in northwestern United States have yielded few such remains. In Kansas and to a lesser extent in Manitoba the bones of marine reptiles, mostly mosasaurs, occur in the Niobrara formation and equivalents, corresponding to an upper part of the Alberta shale.

Overlying the Alberta shale in this area is the Milk River formation, the northward ex-

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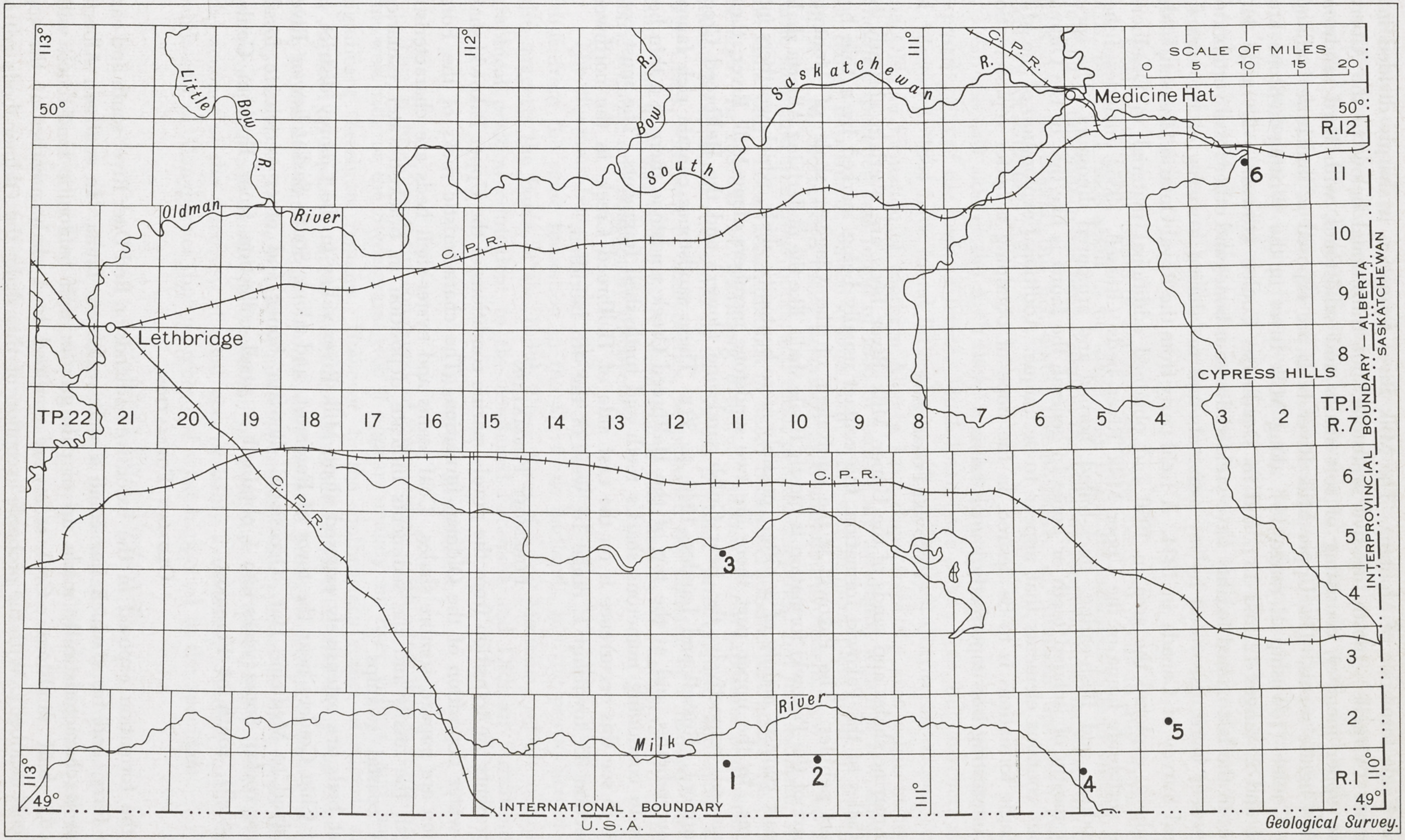

FIGURE 1

Outline map of part of southern Alberta, showing location of areas or sites mentioned: 1. Upper Milk River beds in Deadhorse Coulee; 2. Halfbreed sandstone of Pakowki formation, Halfbreed Coulee; 3. Foremost beds in Etzikom Coulee; 4. Oldman badlands in Milk River and Lost River valleys; 5. Oldman localities near One-Four; 6. Oldman exposures south of Irvine. (Base by Geological Survey of Canada.

tension of the Eagle formation of Montana. The Milk River formation is sharply divided into a lower member (Virgelle), mostly massive sandstone, but transitional below to the Alberta shale, and an upper member, consisting of soft shales and sandstones, with hard sandstone lenses and thin lignite seams. The Upper Milk River beds are exposed in miniature badlands along Police Coulee (township 1, range 13), along Milk River in the Writing-on-Stone area (townships 1 and 2, ranges 12 and 13), and in Deadhorse Coulee (township 2, range 11). The exposures in the last named locality have yielded dinosaur bones and other fossil vertebrates. These occurrences were discovered by my assistants and me during a survey of the area for the Geological Survey of Canada in 1934. A field party from the Royal Ontario Museum, under Mr. L. Sternberg, explored the area in 1950 and obtained additional material in Deadhorse Coulee. The vertebrate fauna of the Upper Milk River beds (Russell, 1935) includes fishes, turtles, crocodiles, and flesh-eating, duck-billed, horned and armoured dinosaurs. The specimens consist mostly of isolated teeth or bones.In general, the fauna is like that of the Oldman formation, but contains elements that appear to be unique. Additional exploration of the Milk River and Eagle formations is to be desired, in the hope of obtaining a better representation of this very interesting but imperfectly known fauna.

Pakowki Formation

The non-marine shales and sands of the Upper Milk River beds are overlain abruptly by the marine shales of the Pakowki formation, the contact usually being marked by a thin bed of black chert pebbles. The Pakowki is the equivalent of the Claggett shale of Montana. The lower part of the Pakowki formation is mostly fissile shale, like the underlying Alberta shale. The upper part consists mainly of a softer, possibly more bentonitic shale, which weathers into rounded forms. In the upper part there are two sandstone members along Milk River; these have been named, respectively, the Bear Gulch sandstone (lower) and the Halfbreed Creek sandstone (upper) (Russell and Landes, 1940, p. 39). These sandstones contain rich faunas of marine invertebrates, and at the top of the Halfbreed Creek sandstone there is a thin bed of conglomerate containing numerous shark's teeth and turtle-shell fragments. The most convenient place to see this occurrence is on the east side of Halfbreed Creek, in the northwest quarter of section 35, township 1, range 10, west of the 4th meridian.

Foremost Formation

This represents the transition from the purely marine conditions of the Upper Pakowki shale to the fresh-water deposition of the Oldman formation. The characteristic rocks of the Foremost formation are impure, sombre shales. Coal seams and oyster-shell beds are characteristic features. Both the fossils and the sediments indicate deposition in brackish-water estuaries, lagoons and coastal swamps.

Foremost beds are extensively exposed along Milk River valley in the Comrey district, in Etzikom and Chin Coulees near the town of Foremost, and along South Saskatchewan River from Bow Island to Medicine Hat. Occasional dinosaur bones and other vertebrate fossils occur in these rocks. Some years ago I obtained a small collection from Etzikom Coulee ("South Coulee"), south of Foremost.

Oldman Formation

This is the formation exposed in the extensive badlands on Red Deer River south and east of Steveville ferry, and from which has come a rich vertebrate fauna. In southern Alberta the formation is characteristically made up of pale grey or buff bentonitic sandstones, with lenses of hard, buff sandstone. Coal seams are confined to a shaly member at the top (Lethbridge coal member). With the probable exception of this shale, the Oldman beds are of

fresh-water deposition, as shown by the numerous fossil molluscs. Exposures of Oldman beds are more extensive on the east side of the area than on the west. A few good outcrops occur along the North Branch of Milk River, in township 2, ranges 19 to 21, and in the Oldman River valley south of Lethbridge. They reappear in the Oldman River valley east of Lethbridge, and are exposed intermittently along this river and the South Saskatchewan River to as far as Medicine Hat. The other extensive area of exposure is Milk River valley, where the Oldman beds form the upper part of the valley walls from Coal Creek to the International Boundary and beyond. There are small areas of badlands outside the river valley, in the vicinity of Comrey, and along Lost River valley.

Isolated dinosaur bones or similar fossils are likely to occur in any exposure of Oldman beds, but good finds seem to be made only where the badlands type of outcrop is developed. Nothing of importance has been found in the Oldman formation on the west side of the Sweetgrass Arch in Alberta, but just across the Boundary in Montana are the "Two Medicine" localities of Gilmore (1917).

On the east side of the Arch there is a small but picturesque area of upper Oldman beds exposed south of the town of Irvine. Much fossil bone occurs here, but searchers since the time of Weston in 1884 have found little of any value. The best discoveries of fossil vertebrates in the Oldman formation of southern Alberta have come from the area adjacent to Milk River. The first specimen was found in 1936 by one of my assistants, within a few hundred yards of the Range Experiment Station at One-Four. This was an incomplete skull of a horned dinosaur, which C. M. Sternberg (1949) described as *Chasmosaurus russelli*, new species. A trionychid turtle shell and numerous bones and teeth of fishes, reptiles, and one mammal, were obtained the same year. Local accumulations of small bones were found just under the Lethbridge coal member. In 1937 C. M. Sternberg explored the area. From exposures northwest of the Range Station he collected two skulls of the horned dinosaur *Monoclonius*, and from the valley of Sage Creek, southeast of Manyberries, he obtained the skeleton of a hooded duck-billed dinosaur. The area was visited by L. Sternberg in 1950 and by W. Langston, Jr., and the writer in 1955, without any noteworthy discoveries.

The dinosaur fauna of the Oldman formation in the Milk River badlands resembles the fauna from the same formation in the Steveville badlands, but the prevalence of *Monoclonius* also suggests the fauna of the Judith River formation of Montana, which occupies a stratigraphical position equivalent to the combined Foremost and Oldman formations.

Bearpaw Formation

This is predominantly composed of marine shale, with a few thin sandstone members. On the west side of the Sweetgrass Arch it appears mainly in river valleys, and has yielded no significant vertebrate remains. However, in the southeastern corner of Alberta the formation is exposed in badlands areas north and east of Manyberries and along the common valley of Manyberries and Sage Creeks. So far only isolated bones or groups of bones have been found in these areas, which are worthy of more exploration. Such bones as have been found are well preserved, and are mostly the vertebrae of mosasaurs and plesiosaurs. There is a circumstantial account of the discovery of what was probably a mosasaur skeleton in the Bearpaw badlands east of Manyberries, but no record of what happened to the specimen.

St. Mary River Formation

On the west side of the Sweetgrass Arch the Bearpaw shale is overlain transitionally by the Blood Reserve or Horsethief sandstone, massive and cliff-forming, and essentially without fossils. Above this are the fresh-water shales and sandstones of the St. Mary River formation. Although it is the stratigraphical equivalent of the lower and middle part of the Edmonton

PLATE 1

Fossiliferous Upper Milk River beds in Deadhorse Coulee, S.W. ¼, Sec. 32, Twp. 1, Rge. 11, W.4th M. (L. S. Russell, Geological Survey of Canada photograph).

PLATE 2

Halfbreed Creek sandstone in Pakowki formation, shark-tooth bed at top; Lsd. 8, Sec. 34, Twp. 1, Rge. 10, W.4th M.; East Butte in background (L. S. Russell, Geological Survey of Canada photogarph).

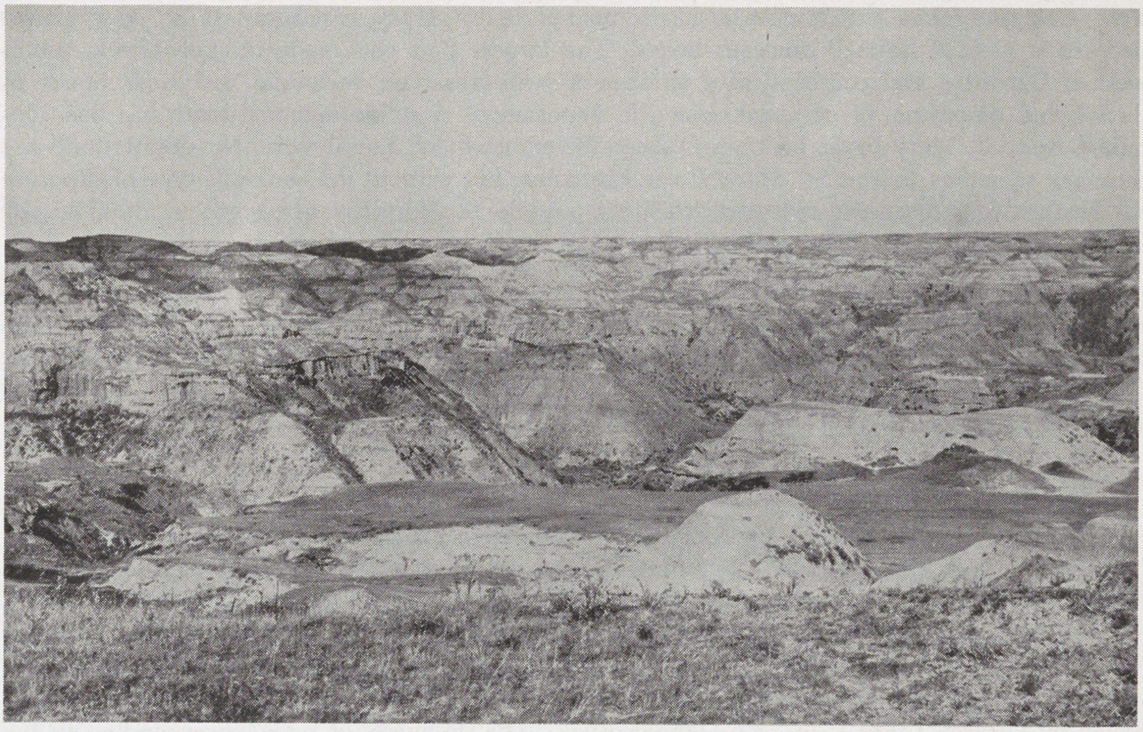

PLATE 3

Badlands in Oldman formation, Milk River valley, Sec. 14, Twp. 1, Rge. 6, W.4th M. (L. S. Russell, Geological Survey of Canada photograph).

PLATE 4

Excavating skull of *Chasmosaurus* in Oldman beds near One-Four; N.E. ¼, Sec. 21, Twp. 2, Rge. 4, W. 4th M. (L. S. Russell, Geological Survey of Canada photograph).

formation of central Alberta, the St. Mary River formation has not yielded anything like the rich vertebrate fauna that occurs in the Edmonton beds. Many exposures of St. Mary River beds have yielded isolated dinosaur bones. The largest find was made on Lee Creek, southwest of Cardston, and consisted of a number of well-preserved vertebrae and limb bones of duck-billed dinosaurs, of no great scientific importance. A single mammal tooth has been obtained from St. Mary River beds on Oldman River, north of Lundbreck. No doubt there are dinosaur skeletons in the St. Mary River formation, but without the badlands type of exposure the chances of these being revealed are slight, and the St. Mary River beds are not lithologically suitable for the development of badlands.

At Scabby Butte, east of Nobleford, important dinosaur remains have been found in beds corresponding to a lower part of the St. Mary River formation but resembling the Edmonton formation in lithology. This locality, although just outside the defined area of the present summary, is interesting as the site of the first discovery, in 1881, of dinosaurs in Alberta (Dawson, 1884, p. 79).

Willow Creek Formation

Overlying the St. Mary River formation are the soft shales and sandstones of the Willow Creek formation. The most characteristic feature of this formation is the colour-banding in pastel shades of red and maroon. This formation weathers into badland forms under suitable conditions, and a striking example occurs at Mokowan Butte, in the Blood Indian reserve, south of Fort Macleod. Unfortunately the formation is not very fossiliferous. The only record of fossil vertebrates from Willow creek beds in this area is that of the fragmentary turtle shell mentioned by Dawson (1884, p. 67) on Oldman River. The discovery of beds corresponding to the Whitemud and Battle formations in the top of the St. Mary River formation (Tozer ,1956, pp. 9, 21) indicates that the Lance equivalent is represented by lower Willow Creek beds. The occurrence of dinosaur bones in these beds is therefore to be expected. In the upper part of the Willow Creek formation one might look for Paleocene mammals.

Other Possible Sources of Fossil Vertebrates

The Willow Creek formation is overlain by the shales and massive sandstones of the Porcupine Hills formation. These, so far, have yielded only leaf impressions and a few molluscs. Paleocene vertebrates may eventually be discovered in these rocks.

On the east side of the Sweetgrass Arch the Bearpaw formation contains a number of sandstone members in the upper part. These are of marine deposition but are known to be contemporary with a portion of the St. Mary River formation on the west. They contain rich deposits of molluscs in places, and might yield the fossils of marine fishes and reptiles. The Bearpaw formation passes into the Eastend formation, which is equivalent to part of the middle Edmonton beds, and in Alberta resembles the Edmonton in having coal seams. Dinosaur bones might be found in the Eastend beds here, but the exposures are few. In the overlying Whitemud and Battle formations very few fossils have been found anywhere. These stratigraphical units have equivalents in the upper part of the Edmonton formation and would contain dinosaur bones if conditions for preservation were suitable. Unconformably on the Battle or lower formations are sandstones and shales which I have identified as the westward extension of the Ravenscrag formation (Paleocene) but which Furnival (1946, p. 104) has relegated in part to the Frenchman formation. The Frenchman formation of Saskatchewan contains the Lance Dinosaur fauna and this might be expected to occur in Alberta. However, no vertebrates have been found as yet, but there is at least one rich bed of Paleocene molluscs.

The youngest formation on the east side is the Cypress Hills conglomerate, which forms a thin capping on the summit of the Cypress Hills. At the eastern extremity of the hills in Sas-

katchewan these beds, much thicker, have yielded a rich fauna of Lower Oligocene mammals. The Alberta development consists only of a coarse conglomerate and it seems unlikely that fossils will be found in it.

REFERENCES

Allan, J. A., and Rutherford, R. L., (1932): The stratigraphical horizon of *Laosaurus minimus* Gilmore. Amer. Jour. Sci., Vol. 24, pp. 225-227.

Dawson, G. M., (1884): Report on the region in the vicinity of the Bow and Belly Rivers, North-West Territory. Geol. Surv. Canada, Rept. Prog. 1882-83-84, pt. C., 169 pp., 4 figs., 6 pls.

Furnival, G. M., (1946): Cypress Lake Map-Area, Saskatchewan. Geol. Surv. Canada, Mem. 242, 161 pp., 5 figs., 4 pl., 2 maps.

Gilmore, C. W., (1917): *Brachyceratops,* a ceratopsian dinosaur from the Two Medicine formation of Montana with notes on associated fossil reptiles. U.S. Geol. Surv., Prof. Paper 103, 45 pp., 57 figs., 3 pls.

(1924): A new species of *Laosaurus,* an ornithischian dinosaur from the Cretaceous of Alberta. Roy. Soc. Canada, Trans., ser. 3, Vol. 18, sec. 4, pp. 1-6, pls. 1, 2.

Russell, L. S., (1935): Fauna of the Upper Milk River beds, southern Alberta. Roy. Soc. Canada, Trans., ser. 3, Vol. 29, sec. 4, pp. 115-128, pls. 1-5.

(1949): The relationships of the Alberta Cretaceous dinosaur "*Laosaurus*" *minimus* Gilmore. Jour. Paleont., Vol. 23, No. 5, pp. 518-520 .

and Landes, R. W., (1940): Geology of the Southern Alberta plains. Geol. Surv. Canada, Mem. 221, 223 pp., 21 figs., 8 pls., 3 maps.

Sternberg, C. M., (1940): Ceratopsidae from Alberta, Jour. Paleont., Vol. 14, no. 5, pp. 468-480, 7 figs.

Tozer, E. T., (1956): Uppermost Cretaceous and Paleocene non-marine molluscan faunas of western Alberta. Geol. Surv. Canada, Mem. 280, 125 pp., 5 figs., 9 pls.

WRITING ON STONE

W .B. GALLUP [1]

Where the Milk River traverses the Sweetgrass Arch, it is rimrocked over a distance of 18 miles by the sandstones of the Milk River formation. The most spectacular and picturesque of these exposures are in the northeastern portion of Twp. 1, Rge. 13, W4th M., where Van Cleeve (locally known as Rocky Coulee) and Police Coulee meet the valley of the Milk River. Here, high sandstone cliffs rim the valley for a distance of two to three miles while to southward in the coulees, fine exposures occur for some distance upstream. The confluence of these three streams gives a somewhat wider than usual valley, permitting several wide meanders of the river along these reaches. On either side, the grassy plains spread away to the horizon which on the south is broken by the West Butte of the Sweetgrass Hills. The Valley floor is well grassed and in part covered with rose thorn, some willow and occasional cottonwoods; such a place as must always become a landmark. It was so recognized by the Plains Indians who called it "Masinasin", later by the Northwest Mounted Police and through the following years by a host of curious tourists. All of these people have carved a record of their visit on the sandstone cliffs at the mouth of and opposite Police Coulee, hence "Writing On Stone".

James Doty is the first white man of record to have visited the place and in his Journal of the year 1855 he wrote as follows: "They (the sandstone rocks) are worn by the action of weather into a thousand fantastic shapes, presenting in places, smooth perpendicular surfaces covered with rude hieroglyphics and representations of men, horses, guns, bows, shields, etc. in the usual Indian style. No doubt this has been done by wandering war parties who have here recounted their coups or feats of war or horse stealing and inscribed them upon these rocks."

The aboriginal pictographs are not numerous. The sandstones are not hard and such marks as might be made with a piece of flint or a point of steel would not last long. Dates left by white adventurers and travellers suggest that within two centuries an engraving would be eroded out unless carved uncommonly deep. The appearance of the horse in some of the pictographs indicates that these were made in the last two centuries. Many of the pictographs appear to have a common theme, a shield. Other weapons appear commonly. Horses appear occasionally and a few lodges are engraved. There is one of a man falling upsidedown. The shields, some of them with men behind them, indicate battle. The horses are riderless and probably not of any significance. The Lodges may signify a camp attacked. The man falling upsidedown indicates an enemy killed in battle. There are totems having a feather motif with symbols engraved upon them. The work does not appear to be done by skilled picture writers as there is not too much association or continuity of story. The writer got the impression that the majority of the etchings were done by what we might term, relatively unlettered individuals who paused to rest and haphazardly recorded some recent adventure. Some drawings are so high above the base of the cliffs that they must have been done by a mounted man. Charlie Russel, the cowboy artist who knew the Indians so well, has done an excellent picture of two warriors, one kneeling on his pony's back carving pictographs on a yellow sandstone cliff. Russel spent his last years on the open range along the Milk River and the drawings in the painting have the same general theme as those at Writing On Stone. It is probable that he had this place in mind when he made the picture.

In the 1880's, "D" Division of the Northwest Mounted Police was headquartered at Fort Macleod and in 1887 posts were established at Milk River Ridge; Kipp; Writing On Stone and Pendant d'Oreille. These were a short day's ride (30 miles) apart.

[1] Consultant Gallup, Buckland and Farney, Calgary, Alberta.

PLATE 1

Police Coulee from the rimrock above the left bank of the Milk River. West Butte may be seen in the distance. The old Police post was near centre of the picture. Names and dates have been carved on the cliffs by men on this detachment.

PLATE 2

Note the warrior in the wolf scalp headdress and the person falling "upside-down" on the right. The shields appear commonly in the pictographs along the left bank.

PLATE 3

The cliffs on the north bank opposite Police Coulee.

PLATE 4

A very crude horse; a man dressed in fringed buckskin (possibly white) on the left, and a belted man on the right. Some of these etchings appear to be imitations by whites and the man in buckskins may be sueh.

PLATE 5

"J.B." has probably claimed an antiquity not in keeping with the date of his visit. The two sparring warriors etched in black pencil (lower centre) may be the work of some modern romanticist playing Indian.

The spring of 1887 was very cold and stormy. The detachments were billeted in tents and strange to the country. Often when on patrol or travelling from one detachment to the other, they were lost during spring blizzards and forced to spend the night on the open prairie. However, the warm summer soon came and their knowledge of the country grew. The assignment of these detachments was to patrol the border, only five miles south of Writing on Stone enforce all custom regulations and to search all travellers for liquor which at that time was forbidden in the territory except under special permit. The men spent their days on the higher ridges covering the country with binoculars and investigating any movement.

Cattlemen in Montana, suffering a rash of sheepmen and seeking unpolluted grass on the Milk River, were returned with their herd south of the 49th Parallel. Packs were stripped from horses and good whisky poured on the thirsty prairie. Blackfeet raiding southward were intercepted and persuaded to return to their reserves.

That fall, the hardened "D" Division was transferred to the Kootenay area to handle troubles with Indians, gold seekers and construction men. They returned the following year to their tents on the Milk River.

In the fall of 1887, Superintendent Neil had recommended the construction of buildings at these posts. This was done in the fall of 1889 when a house with a kitchen lean-to, a stable and a blacksmith shop were erected at Writing On Stone in the south half of Sec. 35, Twp. 1, Rge. 13, W4th M. The amount of country covered by "D" Division on their border patrols is indicated by the fact that during 1889 with 106 horses they patroled 87,739 miles. The thoroughness with which the work was done at Writing On Stone and similar posts is attested by the fact that in 1893, six years after its establishment, the post at Writing On Stone was no longer maintained. Some years afterward, it met the fate that so many of the old cottonwood posts on the plain suffered – the site of an illicit still, it was set to the torch when its then proprietors were advised of impending investigation by the earlier tenants.

Today, comfortable little ranches may be found every 5 or 6 miles along the floor of the valley. There are some fences and a portion of the plains above have been plowed. After the first World War, there was considerable settlement but most of the homesteads were abandoned and the plowed ground went back to grass. The sandstone cliffs show sharply carved initials post-dating Doty's visit by a hundred years. The area is now a Provincial Park and there is a ball diamond and picnic tables, but standing on the northern side of the rim rocks and looking off across Police Coulee toward the purple buttes of the Sweetgrass Hills, it seems that things have not changed so much.

REFERENCES

Russell, L. S. and Landes, R. W. (1940): Geology of the Southern Alberta Plains; Geol. Surv. Canada, Mem. 221, pp. 27.

Turner, John Peter: Northwest Mounted Police, Vol. 2.

Historic Sites of the Province of Alberta, pp. 47.

A SUMMARY OF THE GEOLOGY OF THE CROWSNEST COAL FIELDS AND ADJACENT AREAS

J. CRABB [1]

Introduction

The Crowsnest Coal Fields are located within the Rocky Mountain Area of southeastern British Columbia. The name Crowsnest Coal Basin has also been applied to the same region to denote the Cretaceous basin of deposition in which the coals of the district originated. In the Royal Commission report on coal, B. R. McKay (1946) further subdivides the Crowsnest Coal Fields into the "Fernie Coal Basin on the west and a group of smaller fields to the east . . ." The Fernie Coal Basin, (see Plate) the largest and most important of the Crowsnest coal fields is a pear-shaped-structure of Cretaceous sediments approximately 34 miles long. The narrow end of this structure is pointed northward and terminates approximately 6 miles north of Michel, B.C. The maximum width of the basin, in the vicinity of the Coal Creek mines is approximateyl 12 miles. The southern branch of the Canadian Pacific Railway traverses the northern portion and flanks the western margin of the Fernie basin, thus providing direct rail access to more than one-half of the district.

First coal was mined in 1898 at Coal Creek, located about 5 miles east of Fernie. Since that time, the Crowsnest fields have produced approximately 50 million tons of coal worth over $200,000,000.

Previous Work

Geological work began with G. M. Dawson who examined the area in 1883. Most of the succeeding reports deal with the coal resources of the various mining districts. The only published geological map of the Crowsnest Coal Basin was compiled in 1902 by James McEvoy who was a major contributor to the early mining development. The latest report by C. B. Newmarch (1953) provides a comprehensive review of previous work and includes a valuable addition with respect to the Fernie Coal area.

Topography

Relief in the area is low to moderate, varying from 3,200 feet to 4,500 feet. Present topography is largely an expression of the erosional resistance of bedrock, the distribution of which has been determined by geological structure. Highest elevations are along the Palaeozoic ranges which border the maturely dissected plateau of the Fernie Coal Basin. In general, the Palaeozoic formations form the more rugged scenic profiles whereas the more subdued and drab-colored landscapes are underlain by Mesozoic strata.

Glaciation

Although previous authors mention a continental ice sheet covering the map area, proof of its existence is not evident. Alpine glaciation has, however, formed cirque-like basins at the headwaters of many creeks, and the U-shaped profile of Elk Valley suggests valley glaciation.

Perhaps the most remarkable late-glacial feature is a gravel bench which can be traced along the walls of the Elk Valley from a point near Morrissey, northward for a distance of at least 30 miles. Throughout its extent, this level lies at about the same elevation as Crowsnest Pass (4,450′) to which point it can also be traced. In some localities, notably Michel, the gravels are well rounded and sorted. Interbands of sand are common, and bedding dips steeply out-

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ward toward the valleys. Beneath the alluvial gravels, the floor of the Elk Valley from Sparwood to Morrissey is covered with a fairly thiick deposit of light-colored, glacial-like clays which extends up some of the tributary streams and is draped up the valley walls for an undetermined distance. Fish remains have been reported found in these clays near Fernie. All the above data strongly suggest that the Elk and tributary valleys were once occupied by a lake which varied in depth from approximately zero at Crowsnest to a maximum of about 1,400 feet in the vicinity of Morrissey. The width of the elevated gravel beach and the amount of clay on the floor of the Elk valley indicates that water was maintained at this level over a long interval. The lake probably drained through Crowsnest Pass eastward into Alberta. The comparatively wide gap of the pass, out of adjustment with the present creek, corroborates the latter hypothesis.

The lake was caused by damming of the narrow part of the Elk Valley east of Elko . The damming agency is not now apparent, but was likely a glacier occupying the Kootenay Valley. Such an ice mass would block tributary streams of the Kootenay, impounding their waters. The Kootenay Valley itself, displays pronounced evidence of glaciation. From the village of Wardner south, knob and kettle topography is prominent while throughout, striking lineal features indicate the southward movement of ice down the Rocky Mountain Trench. Eratics of Beltian rocks are common on the Palaeozoic slopes in the reentrant east of Elko. In this same vicinity, the old high-level river channel, now occupied by Silver Springs Lakes, was probably carved by the Elk River as the ice dam retreated.

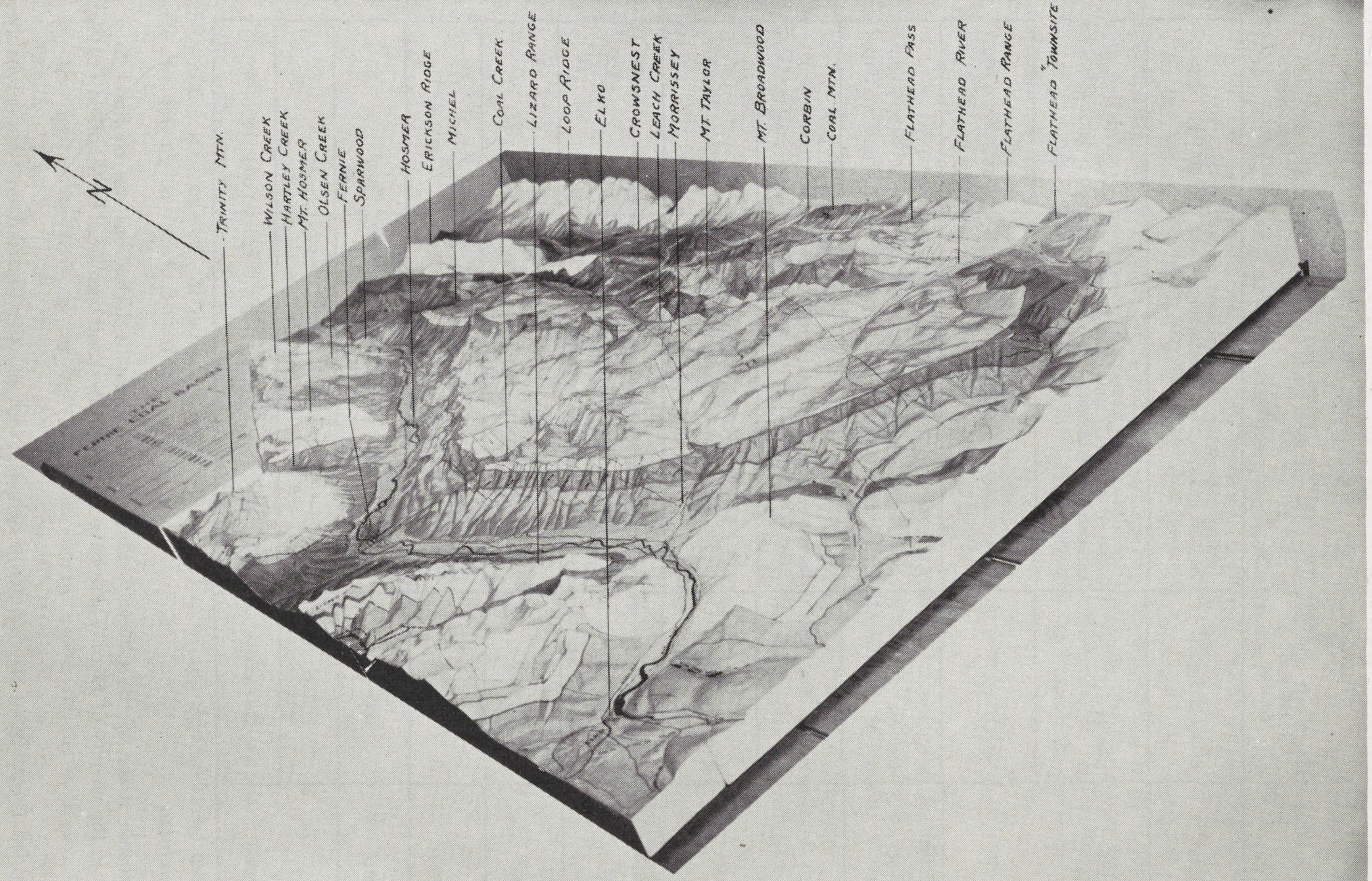
Stratigraphy and Correlation

With the exception of a few minor igneous intrusions near the east margin of the Rocky Mountain Trench, all the exposed rocks are of sedimentary origin. These range in age from late Precambian to Recent and have a combined thickness of 18,000 feet or more. A brief outline of their lithology, correlation and thickness is given on the following table of formations.

CROWSNEST COAL BASIN AND VICINITY

TABLE OF FORMATIONS

System or Series	*Formation or Member*	*Lithology*	*Thickness West*	*East*
Recent and Pleistocene	—	Lake clays, gravels and little till	0-300′?	
		Angular Unconformity		
Lower Cretaceous	Blairmore (Elk Member included)	Conglomerates, sandstones with cannel coal overlain by vari-colored shales	2,300′	1,000′?
Lower Cretaceous or Upper Jurassic	Kootenay Coal Measures	Sandstones, carbonaceous shales some conglomerates and 4-12 mineable coal seams. Non-marine	2,550′	1,000′?
Jurassic	Fernie	Grey to black phosphatic shales, some sandstone and limestone horizons. Largely marine	3,000′	1,100′
		Disconformity		
Triassic	Spray River	Thin bedded, reddish weathering black, laminated, sandy shale. Some bluish impure dolomite	1,800′?	350′
		Disconformity?		



THE CROWSNEST COALFIELDS
(RELIEF MODEL)
VARYING SHADES REPRESENT GEOLOGICAL FORMATIONS

CROWSNEST COAL BASIN AND VICINITY

TABLE OF FORMATIONS (continued)

System or Series	*Formation Member*	*Lithology*	*Thickness West*	*East*
Permo - Penn	Rocky Mountain	Quartzitic dolomite and limestone, interbedded quartzite, buff-weathering. Chert horizons and, nodular siliceous phosphate	700′	1,100′
Mississippian	Rundle	Crystalline and fragmental limestones, some dolostones, some chert horizons, massive cliff-forming, porous zones present.	2,500′	2,800′?
	Banff	Dark, argillaceous, dense, hard limestones, chert nodules and lenses prominent, nonfossiliferous	770′	1,070′?
Mississippian?	Exshaw	Hard, black, thin bedded, fissile siliceous shale. Some limy and phosphatic horizons, pyritic near base. Fossils rare.	270′	45′
		Disconformity		
Upper Devonian	Palliser	Dark grey, dense, massive, mottled limestone. Cliff-forming. Few silicified fossils.	950′	900′
	Alexo	Light grey, quartzite (Broadwood member) underlain by laminated, silty, crenulated dolomite.	300′	270′
	Upper and Lower Fairholme	Dark grey argillaceous limestone with dolomites in the lower section. In some localities biohermal and biostromal	1,400′ -	1,500′
		Disconformity		
Middle Cambrian	Elko	Siliceous limestone	90′	
Lower Cambrian	Burton	Greenish-black shale with limestone beds. Hematite conglomerate at base.	78′	
		Locally Disconformable		
Precambrian	Roosville	Massive, green laminated metargillite with Algal structures near top	1,000′	
	Phillips	Predominantly red and purple metargillites, sandstones and quartzites	500′	
(Galton Series)	Gateway	Massive, siliceous, limestone, and dolomite overlain by sandy argillites	1,000′	

(a) Precambrian

Proterozoic strata of the Gateway, Phillips, and Roosville formations are confined to a small area in the vicinity of Elko. These have been described and correlated by Schofield (1914-1922).

Undivided Precambrian Strata outcrop behind (west of) the Lizard Range and probably belong lower in the series than those at Elko.

(b) Palaeozoic Formations

Palaeozoic formations of the map area may be divided into three large outcrop belts:

(1) Along the south and west side of the Fernie Coal Basin.
(2) The Loop and Erickson ridges, located in the north-central portion of the map.
(3) The Flathead and Highrock ranges along the east margin of the map.

In the latter belt, sections near Crowsnest have been described and correlated in various published reports. No complete Palaeozoic sections have been measured in the Loop-Erickson ridge belt because of severe faulting and folding. Until recently, little attention was given to the Palaeozoic outcrops west of the Crowsnest basin. In the western belt, good sections are available at a number of localities noteworthy among which are the Lizard Range exposures, where the sequence is overturned.

A summary of the more important stratigraphic changes which take place from the east side to the west side of the Crowsnest basin are:-

(1) In general, the Fairholme formation contains a larger percentage of impurities. On the back slopes of the Lizard Range, this formation exhibits pronounced "reef" development, which gradually diminishes and finally disappears southward at Broadwood Mountain.

(2) A partial equivalent to the Alexo, herewith termed "Broadwood Quartzite" member, is a well sorted, quartz sand. This member is prominent throughout the extent of the Lizard Range. The following section was measured in the south-facing draw approximately 3 miles east of Elko.

Base of Palliser

Alexo Formation		Thin-bedded buff weathering silty limestone	80 feet
	Broadwood Member	White to grey calcarous quartzite buff to pink weathering	85 feet
		Shaly quartzite	25 feet
		Light grey quartzite	90 feet
		Dark grey calcareous silt	25 feet

Top of Fairholme

(3) As a lithologic unit, the Exshaw thickens rapidly westward.

Although a thickness of 5,000 feet has been assigned to the Rundle formation at Crowsnest, it is the author's opinion that the Rundle and Banff formation have been repeated by faulting as far south as Corbin, B.C. As indicated on the above table, the approximated true thickness of the Rundle in this area is 2,800 feet.

(c) Mesozoic Formations:

Mesozoic sediments form the large, elliptical, central portion of the map area. Reddish-weathering, Triassic, (Spray River) strata are generally exposed along the rim with successively younger formations outcropping in bands toward the centre of the Fernie Basin Weakly resistant Fernie shales underlie many of the stream valleys. Except where erosion has down-

cut through the rim of the Coal Basin, the Kootenay and overlying Blairmore formations outcrop at high elevations.

The lack of good exposures and the contorted nature of the Fernie formation along the west side of the area prevents measurement of a complete section. In the vicinity of Fernie, this formation has undoubtedly been repeated, but partial stratigraphic sections, drill holes and graphic projection indicate a possible thickness of 3,000 feet.

Similar difficulties are confronted in measuring the Spray River formation, which, in addition, has a lithology that closely resembles some horizons of the Fernie formation.

Good Kootenay and Blairmore sections are available at numerous localities along the western rim of the Fernie Coal Basin.

All four of the Mesozoic formations thicken noticeably in a westward direction. In particular, the conglomeratic "Elk" member of the Blairmore forms a giant wedge which tapers from 1,700 feet at Coal Creek, to a few hundred near Corbin.

Most pronounced lithologic changes occur in the Kootenay and Blairmore formations. The Kootenay, for example, contains 12 mineable seams in the vicinity of Fernie, but only four eastward on Mount Taylor.

Structural Geology

For the sake of brevity, only the more prominent structural features can be discussed. These form three natural geological divisions:

WEST SIDE:

(1) Elko syncline

Precambrian strata near Elko are folded in a broad southerly-plunging syncline. The southern end of the structure is truncated by a wide near-vertical shear zone which strikes northwest through the canyons of the Elk and Southfork Rivers. The east limb of the Elko syncline is thrust-faulted on to the Palaeozoic slopes of the Lizard Range and Mount Broadwood. In the latter area Roosville strata have been brought into contact with the Rundle formation. On the opposite (north) side of the Elk River, the east limit of the Elko syncline displays a large drag fold into the fault.

(2) Broadwood Anticline

Palaeozoic formation of Mount Broadwood are folded in a slightly overturned, asymmetric anticline, the axis of which strikes northwest and plunges under the Lizard Range. The core of the fold is cut by a high-angle west-dipping thrust? fault, which decreases in throw to the north.

(3) Lizard Overthrust

The Lizard Range, Mount Fernie, Mount Proctor, and Mount Hosmer are largely comprised of an overturned sequence of Palaeozoic formations which belong to one or more overthrust sheets.

The structure of the Lizard Range represents the inverted limb of an overturned anticline that has been faulted over the Broadwood anticline. Fernie shales outcrop between these two structures at the south end of the range, and are also exposed in a window through the Lizard overthrust in the valley of Sand Creek. The Lizard Overthrust and the previously-mentioned Precambrian thrust east of Elko, are probably the same fault. Two other smaller faults to the

west have resulted in a slice of Precambrian rocks between the inverted sequence and the normal Palaeozoic sequence that borders the Rocky Mountain Trench.

The major structure of Mount Fernie, Mount Trinity, and Mount Proctor, resembles that of the Lizards except that the upper or normal limb of the anticline is here present. The approximate 30° divergence in strike between these two units suggest a separate thrust sheet. A series of smaller thrusts have disturbed the core of the fold where Palliser beds are repeated two or three times.

The Palaeozoic formations of Mount Hosmer are in an erosional remnant (or klippe) of a former large-scale anticline. Remaining is the vertical to overturned lower limb. The underlying fault is folded and pitches southward from the headwaters of Spruce Creek.

At Hartley Creek, where the overthrust may be clearly observed, Devonian and Mississippian formations have been brought into contact with Fernie shales, elsewhere, the klippe rests largely upon Triassic or Jurassic beds.

(4) Structures, from Mount Hosmer north to Wilson Creek, involve Pennsylvanian or younger strata which are variously folded and faulted. The valley of Olsen Creek follows a synclinal axis in the Rocky Mountain formation. At the entrance of Wilson Creek farther north, Spray River and Rocky Mountain formations are overturned. At higher elevations, in the same vicinity, a fault has caused a thin slice of Rundle to be overlain by normal Rocky Mountain beds.

CENTRAL AREA:

(1) The Fernie Coal Basin

The largest synclinal axis starts at the southeast corner of the basin, trends northwest to the Flathead River and then swings northeast in a large arc to Mount Taylor. A second synclinal axis commences near the north end of Mount Taylor and strikes northwest through Sparwood ridge and the Michel mines. A third and less pronounced syncline may be followed from Hosmer southward to Coal Creek where it appears to die out. This latter fold is a possible southward continuation of the previously-mentioned Olsen Creek syncline.

A thrust fault, traceable from Martin Creek northward along the west wall of Leach Creek to the forestry lookout, has caused Kootenay to override Blairmore.

Fernie strata adjacent to the west margin of the Coal Measures are folded into one or more anticlines, the axes of which are parallel to the Kootenay outcrops. Westward, across the remaining width of the Elk Valley, Fernie shale exposures are largely west-dipping and represent a repeated sequence. Crustal shortening in this "foreland" of the various overthrusts has been localized in the Fernie formation because of its structural incompetency.

A comparison of the highly deformed east margin of the Cretaceous coal basin, with the relatively uniform dips along the west side, suggests that the Crowsnest Basin has been shoved bodily eastward against the Palaeozoic masses of the Flathead and Highrock Ranges.

(2) Loop and Erickson Ridges

Along Loop and Erickson Ridges, Rocky Mountain and Rundle formations are exposed in a complex, overturned and faulted anticline. The structure is doubly-plunging, terminating southward at Mount Taylor and northward (off the map area) in the Greenhills Range. On the west side of Loop Ridge, Kootenay and Rundle formations are in contact along a west-dipping fault. Erickson Ridge separates, an echelon, the north end of the Fernie Coal Basin from the south end of Upper Elk Coalfield.

EAST SIDE:

The large mass of the Highrock and Flathead Ranges consist mainly of a single, normal, west-dipping thrust-sheet, underlain presumably by the Lewis fault. The west side of the block is variously folded, particularly south of Flathead Pass where Upper Palaeozoic rocks are exposed in a series of anticlines and synclines. Between the Erickson-Loop Ridges and the Highrock Ranges, the structure is essentially synclinal.

The low-lying Mesozoic outcrops in the vicinity of Flathead "Townsite" present one of the most interesting and difficult structural problems of the entire area. Along the east and north sides, Kootenay (?) beds are in fault contact with various Precambrian and Palaeozoic formations. As demonstrated by P. de Bethume (1936) the Lehigh Lake-Piton fault(s) is probably an overthrust. A portion of the south side appears to be a normal sequence on the north plunging MacDonald Range anticline. The remaining southeast side is in fault contact with upper Palaeozoic strata.

Economic Geology

(1) Coal

The coal seams of the Crowsnest Basin have long been the outstanding natural resources of the district. Remaining reserves are estimated in the billions of tons but published figures are somewhat misleading. For example, in the estimate prepared for the Royal Commission (1947) the reserve of probable recoverable coal in the Crowsnest Fields is given as 3 1/3 billion tons. This, however, includes coal in large disturbed areas, where present-day mining is uneconomical or prohibited by other factors. Furthermore, due to the increasing displacement of coal as fuel, by oil and gas, future importance should be attached primarily to the high-quality coking seams. These are confined to the upper part of the Kootenay formation and hence comprise only about 1/3 or less of the total reserves.

(2) Phosphate

In addition to its substantial coal resources, the Crowsnest Basin contains some of the largest deposits of sedimentary phosphate in the Canadian Rockies. These are of low grade and occur in a variety of types near the Palaeozoic-Mesozoic contact. To date, the phosphate deposits have remained unexploited.

(3) Petroleum and Natural Gas

Few attempts have been made to drill for oil in mountainous terrain because the existence of oil in such regions has been thought unlikely. Oil exploration is proceeding however in the Fernie district. This has been due to several factors including the following: Wet gas has been recently discovered to the east at Pincher Creek and the area adjoining the Lewis overthrust; the Crowsnest Coal Basin is the largest, relatively undisturbed body of Mesozoic sediments in the Rocky Mountain Area; several formations, particularly the Rundle and Fairholme contain petroliferous or porous zones.

Some of the problems met here in connection with oil exploration are similar to those of the foothills belt. For example, surface structures do not necessarily persist to depth, especially in the Fernie formation which appears to be folded independently of the strata above and below. A problem not encountered in the foothills is the unknown effects of metamorphism (as reflected by the high degree of induration of the Mesozoic rocks and the higher-rank coal, as compared to Alberta).

(4) *Limestone and Building Materials*

Several Limestone horizons of the Rundle formation are suitable in quality for the production of lime or cement. These outcrop along the railroad at Erickson Ridge east of Michel and near the tunnel, east of Elko. Good quality red and green flagstone is available from the Roosville and Phillips formations near Elko.

(5) *Base Metals*

Numerous vein-filled types of deposits have been prospected along the east wall of the Rocky Mountain Trench, but no economic occurrences have been reported to date.

REFERENCES

Bethune de, P. (1936): Un cas d'involution de nappes du second genre dans les Montagnes Rocheuses du Canada. Memoires de l'Institut Geologique de l'Universite de Louvain, Tome X.

Dawson, G. M. (1885): Preliminary Report on the Physical and Geological Features of that portion of the Rocky Mountains between Latitudes 49° and 51° 30', Geol. Surv., Can., Ann. Rept.

McEvoy, J. (1902): Geological and Topographical Map of Crowsnest Coal Fields, Geol. Surv., Can., Map No. 767.

MacKay, B. R. (1946): Coal Reserves of Canada, Reprint of Chapter 1 and Appendix A of Report of the Royal Commission on Coal, 1946, Geol. Surv. Can.

Newmarch, C. B. (1953): Geology of the Crowsnest Coal Basin. B.C. Dept. of Mines Bull. No. 33.

Schofield, S. J. (1914): The Precambrian (Beltian) Rocks of Southeastern British Columbia and their Correlation, Geol. Surv. Can. Museum Bull. No. 2.

(1922): Relationship of the Precambrian (Beltian) Terrain to the Lower Cambrian Strata of southeastern British Columbia, Geol. Surv. Can., Bull. No. 35.

THE USE OF THE SEISMOGRAPH TOOL IN THE WESTERN CANADIAN FOOTHILLS

L. H. REED [1]

Previous papers have covered in considerable detail the technical phase of seismic exploration in the foothills. The purpose of this paper is to discuss the use and potential value of the seismic tool in foothills exploration.

From an economic point of view, the foothills area is one of the most expensive to seismograph. This is the reason, no doubt, which has restricted the amount of such work accomplished to date. However, exploration thinking seems to be attaching increasing importance to the near mountain areas as the efficiency of the exploration techniques and the desirability of the prolific foothills oil and gas fields both increase. If this trend continues, the experience gained in this area will certainly result in a more rapid improvement of techniques such as has occurred in the plains areas. Recent advances in instrumentation and data presentation will also be helpful.

In designing a successful foothills seismic program, there are certain factors which are essential:

(1) The geologist and geophysicist should work very closely together so that the seismic personnel will have at their disposal as complete a knowledge of the area as possible. Such things as dominant structural forces and regional trends, anticipated magnitude of structure, estimated depth of Palaeozoic, information on the overlying Mesozoic section and any other geologic data are all helpful in designing a program. It should be remembered, too, that the nature of the structures and the accessibility factor usually preclude anything as simple as the standard grid comonly used on the plains.

(2) Bearing in mind all the information available on the area, the geophysicist should draw up a program designed to achieve the specific objectives originally outlined. The principle of shooting a reconnaissance pattern, followed, if justified, by an expansion of the control in order to properly evaluate the leads, is a sound one. The relative efficacy of the two types of seismic shooting should be determined to some degree during the initial work. This information is vitally important in order that the proper degree of flexibility and maximum effectiveness may be attained.

(3) The mobile equipment should be well adapted to the terrain which must be traversed. Various types of conventional two-wheeled drive, four wheel drive and tracked equipment have been used successfully, depending upon the nature of the country and the type of program (Plates 1 and 2).

(4) A proper balance between the operational sections of the seismic crew should be maintained for refraction shooting. The most expensive item is the recording crew and a maximum output here is desirable. Next to this come the drills. Even though they are also expensive, a careful scrutiny of the operation should be made to insure that maximum efficiency of the drills is not being attained at the expense of decreased recording crew efficiency.

(5) Field planning is even more critical in a refraction program than in the more conventional plains reflection surveys. This is because the refraction operation frequently involves two surveying crews, three or four drilling crews, two or three shooting units, a recording crew and one or two bulldozing crews operating in widely separated parts of the project, resulting in a scattered activity which must be properly co-ordinated by the party chief.

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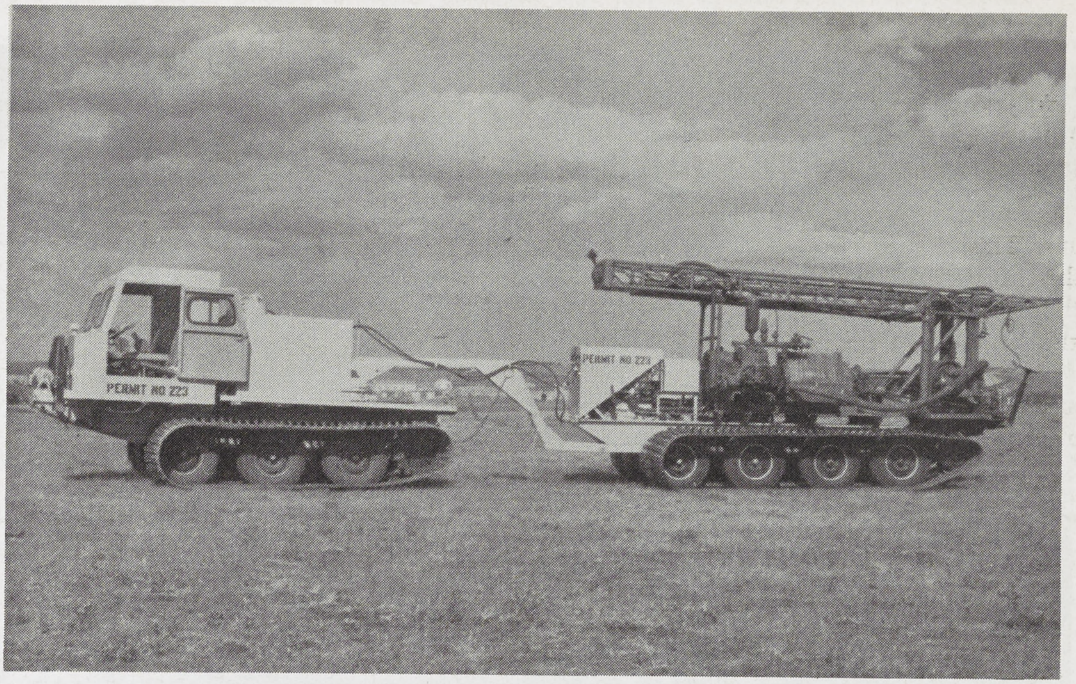


PLATE 1(a)

"Scout" Track Truck and Powered Trailer (Designed to carry larger drill).

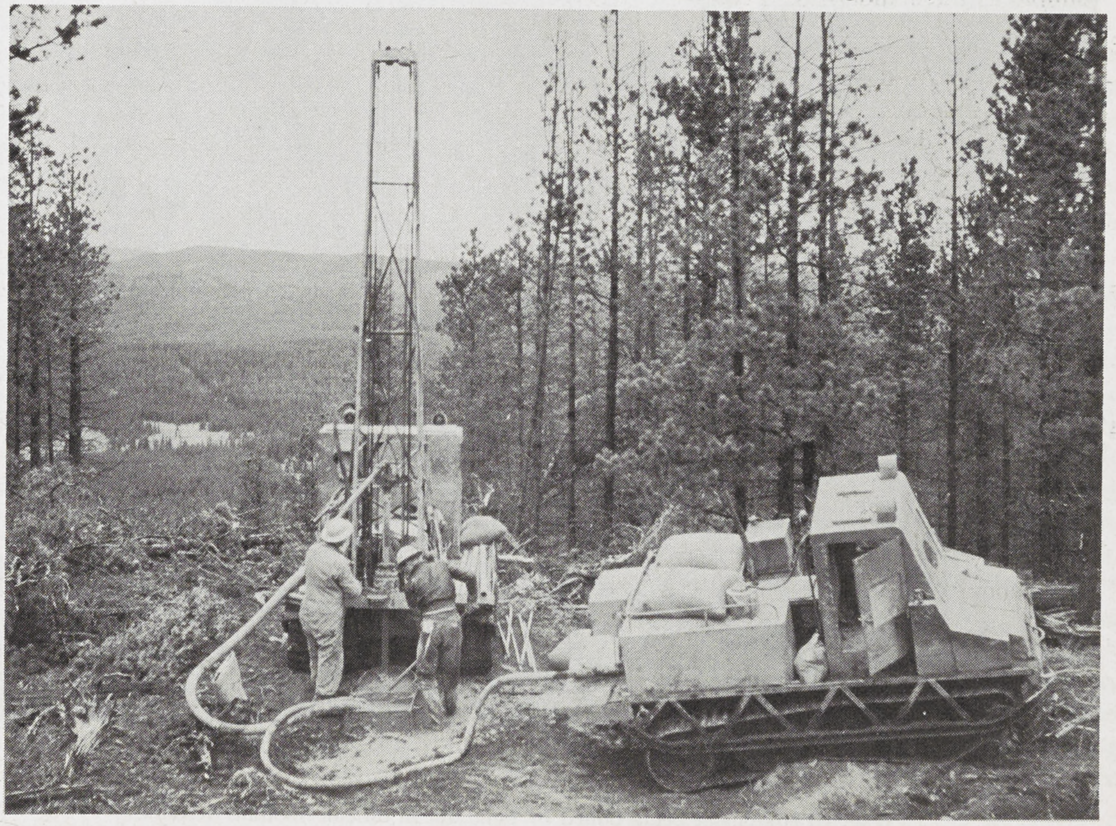


PLATE 1(b)

Bombardier mounted small drill and water truck at foothills shot point location.

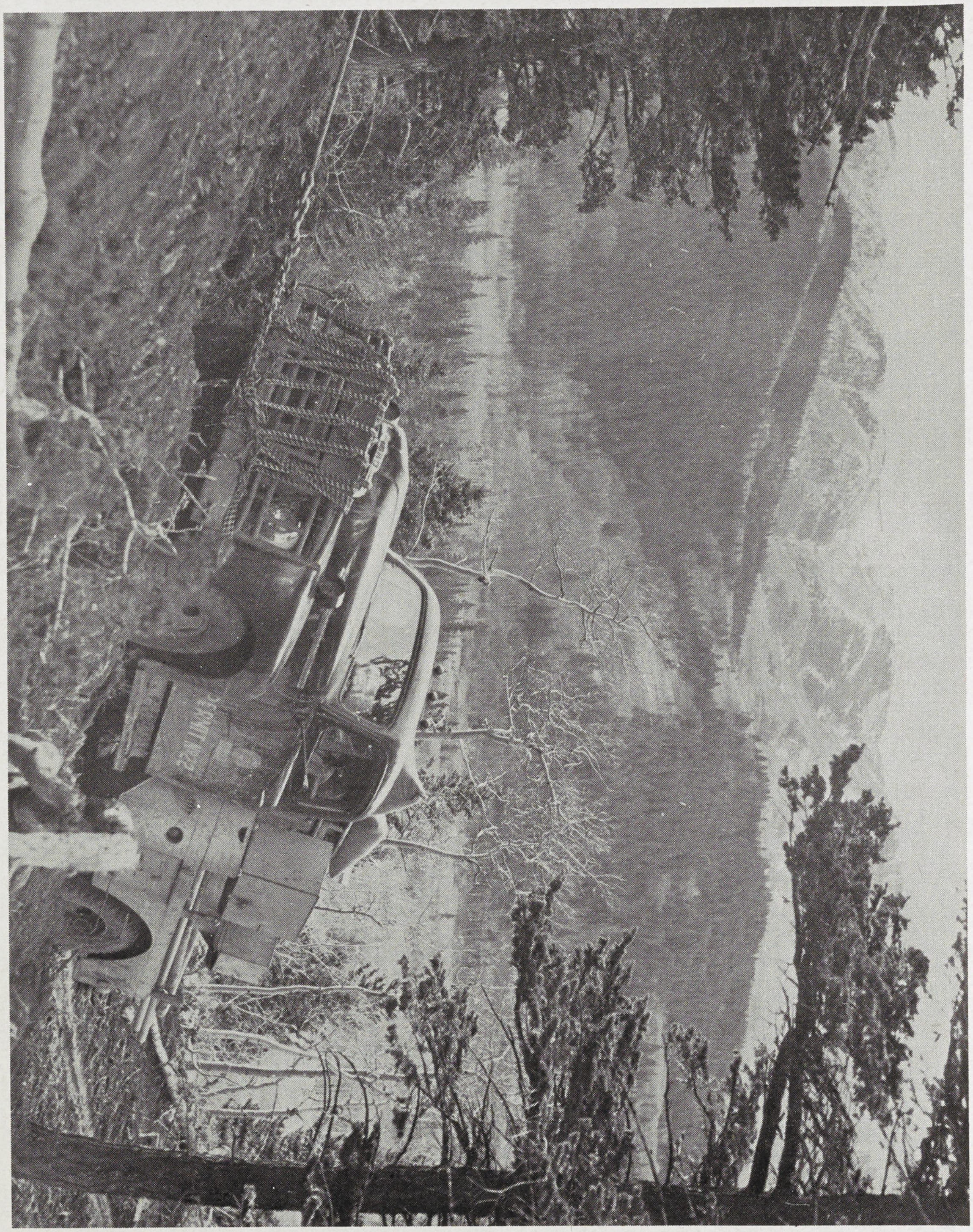


PLATE 2

Wheeled equipment being pulled by bulldozer in dificult foothills terrain.

The use of aerial photos for field planning and survey information is very helpful.

Companies with foothills interests can be classified somewhere between the two extreme groups — those which have a background of experience in the area from which they have devised a definite approach and those which are relatively inexperienced and are in the process of finding the least painful way to become initiated. One fact which has been generally accepted is that in some areas refraction will be the primary tool, while in others, reflection will be better. Some happy combination of the two will most effectively provide the answers in yet other areas.

With all the geologic information at his disposal and a clear understanding of the basic objectives in mind, the seismologist is in a position to devise a seismic approach to suit the circumstances. Usually, as the complexity of the Palaeozoic horizon increases, so does the emphasis which will be placed on refraction shooting. The reason for this is that this method is less affected by local irregularities and tends to present a simplified representation of the primary structures. The character and nature of the refraction seismograms make it far easier to position the top of the Palaeozoic section than do reflection seismograms (Figure 1). It is usually possible to jump-correlate from one adjacent line to the next with considerable degree of reliability ,which minimizes the need for continuous ties in areas of difficult terrain.

Another factor of economic significance is the fewer shot-holes needed and the less rigorous shot-hole positions requirements in refraction as compared to reflection shooting. This, too, becomes more important as the drilling conditions and surface topography becomes more difficult.

The chief advantages of reflection shooting are that under favorable circumstances, it provides information throughout the section, and that it possesses greater resolving power. Its main weaknesses in disturbed areas are the lack of reflection continuity and absence of reflection events with diagnostic correlation properties. Whereas in a normally undisturbed foothills area the top of the Palaeozoic reflection event stands out, in disturbed areas it can become weaker than overlying Mesozoic events which may be quite strong locally. Where complex faulting is present, none of the events persists over an appreciable area so that local dip information is the best that reflection shooting can provide. The usefulness of this information is considerably enhanced by combining it with refraction data.

There are some natural obstacles which hinder the seismic evaluation of a foothills area by either method. In steeply dipping, complexly folded and faulted areas, ambiguity or absence of refraction or reflections on the seismograms frequently occur. Severe changes in geologic section, often accompanied by marked sectional velocity changes, can cause trouble. The effects of this phenomenon will be less marked as the industry acquires more deep hole velocity information, with special emphasis on the continuous velocity type. It is quite possible that, down the road, seismologists may acquire a skill in estimating velocities by considering carefully the anticipated geologic section as supplied by geologists and utilizing known velocity data in the general area. Even now, with the scarcity of velocity information in foothills areas, a ten percent probable error in predicted absolute depth would be high, and more accurate representations should be common, based on refraction measurements. Because the refraction shot-to-detector distance is usually in the order of six miles, it is possible on dip lines for severe velocity variations to exist between the two ends of the ray path. When this occurs (and at any other time when velocities change abruptly) a problem arises in separating the pseudo effect from real structure. This can usually be solved in areas of interest by judiciously combining the in-line and broadside types of refraction shooting and paying close attention to the known geology (Figure 2).

The presence of uncontrolled velocity variations lessens the seismic resolving power. If

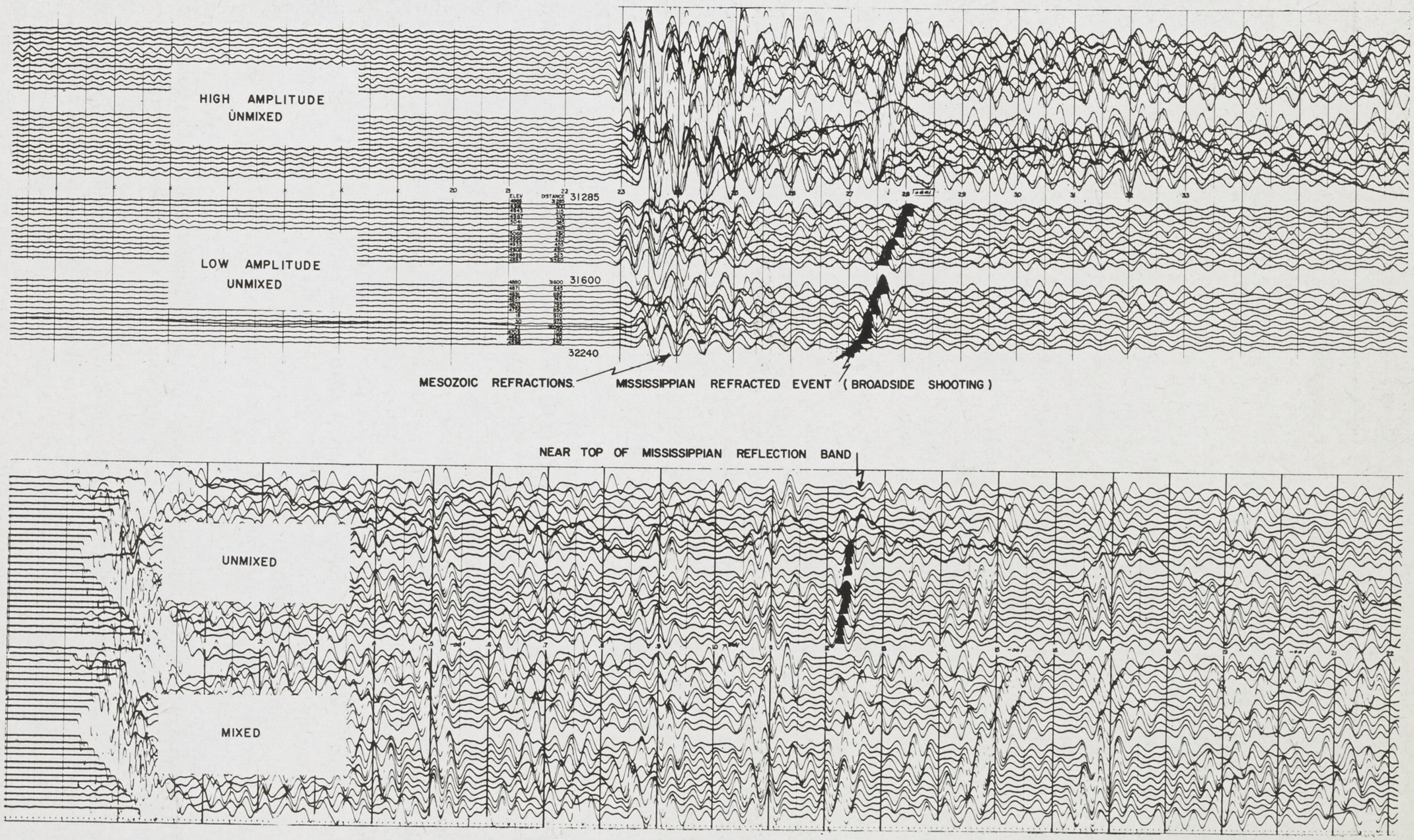


FIGURE 1

TYPICAL REFLECTION AND REFRACTION SEISMOGRAMS IN A DISTURBED FOOTHILLS LOCATION. NOTE THE SUPERIOR CORRELATION QUALITIES OF THE REFRACTION EVENT. MISSISSIPPIAN DEPTH APPROXIMATELY 9000 ft.

Figure 2.

Figure 2(a)

CROSS SECTION OF IN-LINE REFRACTION ARRANGEMENT

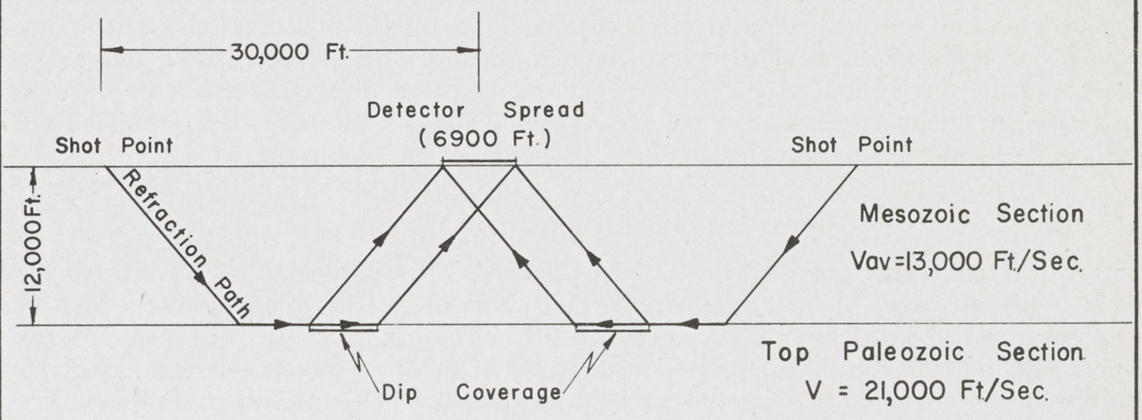
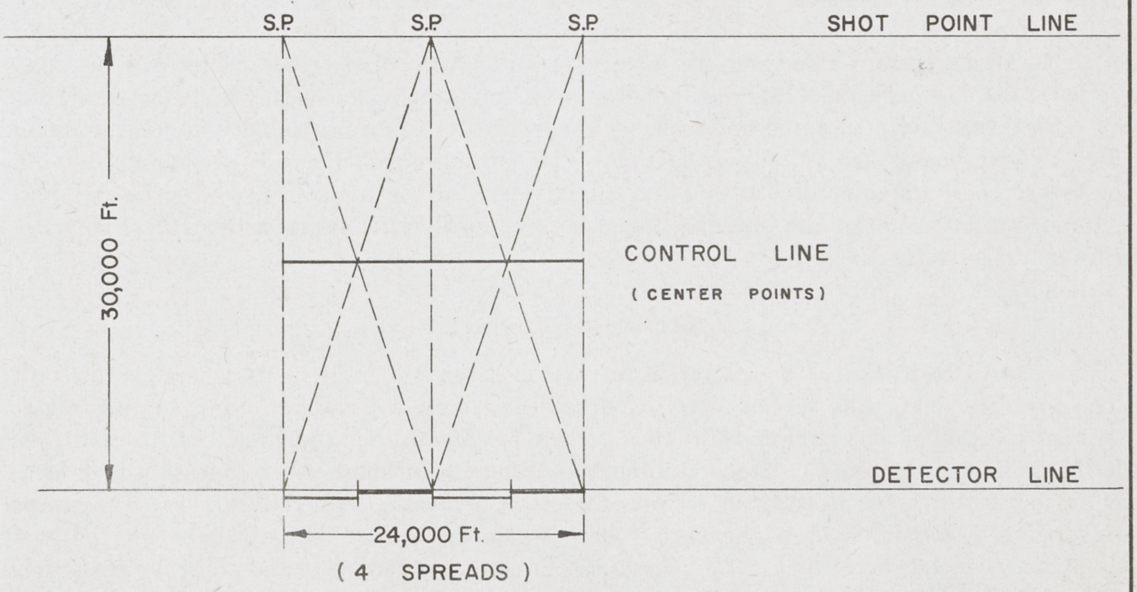


Figure 2(b)

PLAN OF TYPICAL BROADSIDE REFRACTION ARRANGEMENT



no compensation is made in the computations for extreme velocity changes, considerable error will result in relative relationships. Usually, the nearer two locations lie to a common Mesozoic strike line, the more accurate the seismic relatiship between the two will be.

Steep dips and faulting present added difficulties to the seismologist in these areas. The most accurate representation of a steeply dipping bed is supplied by the shooting of reflection cross-spreads in order to properly measure the three dimensional effect. The refraction ray includes variables at the shot end, along the refractor travel path and at the detector end, the effects of which are often difficult to separate. The best approach, in such a situation, is to maintain a control line orientation as nearly perpendicular to strike as possible. Often, the positioning of a Palaeozoic fault edge by refraction cannot be done very accurately due to the geometry of the wave paths. Anticlinal turnover and fault edge diffraction effects are difficult to separate. A situation such as this can sometimes be satisfactorily resolved by combining a small amount of strategic reflection shooting with the refraction information.

Operations — Refraction Seismograph

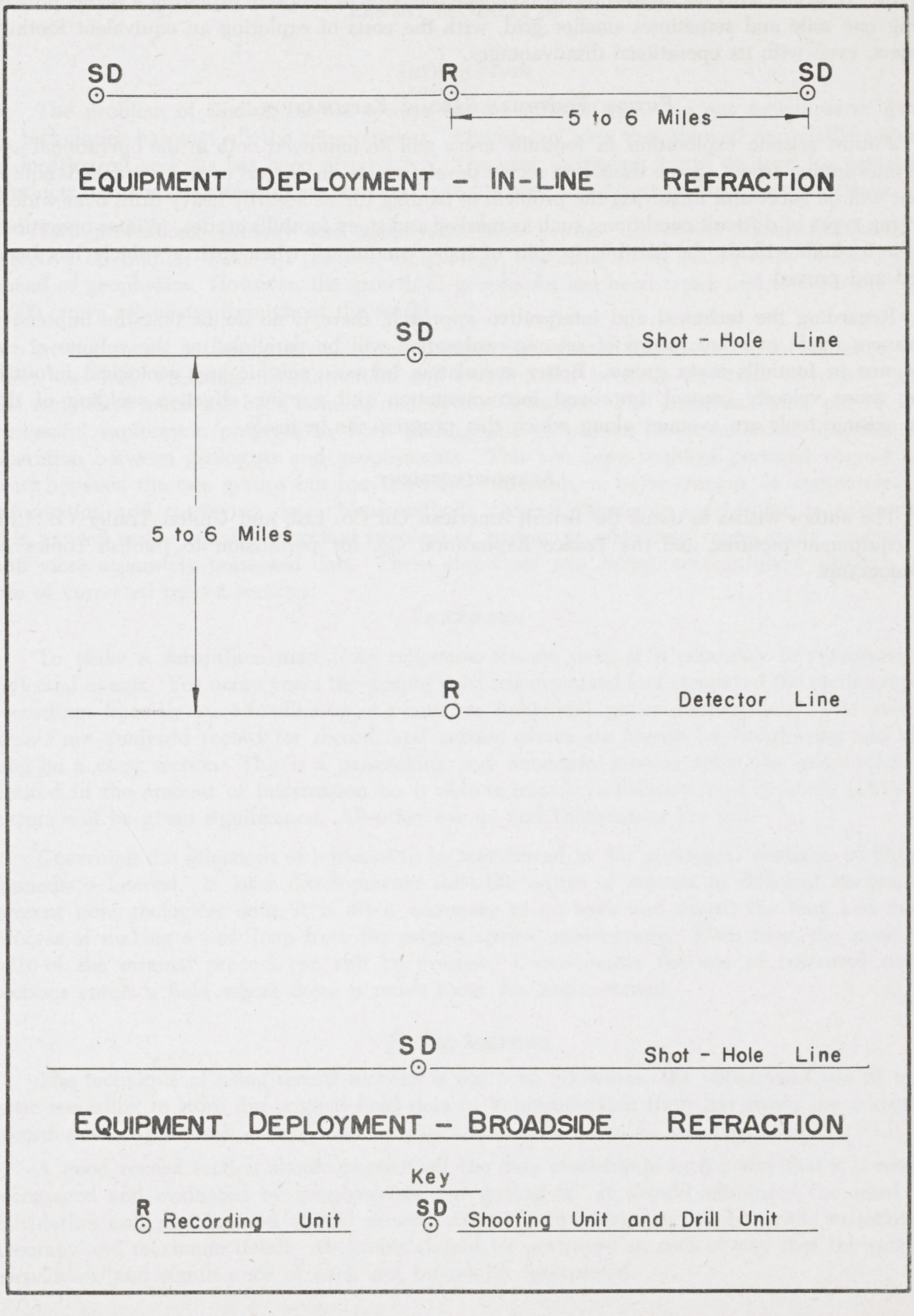
From an operational point of view, the problem has increased many fold for this type of shooting. Instead of all units staying together and working at the same location, there is now a minimum of three groups, each separate from the other by six miles or more. Figure 3 shows how the operational groups are deployed for broadside or in-line refraction shooting. Most operators have found that a recording crew, two shooting units and enough drills to satisfy their requirements provides the desirable compromise for field efficiency. With this arrangement, broadside shooting from two sides or in-line shooting from two directions will be conducted into the same "spread" of detectors on the detector line (Figure 3). Sometimes efficiency can be increased by adding another shooting unit so that a combination of broadside and in-line control can be acquired by shooting into the same detector lay-out.

Normally, the detector line should be bulldozed as straight as possible, with detours skirting some surface features. The broadside shot-hole lines need not be straight and bulldozing is necessary only to provide accessibly to the general shot-point locations. It is not even essential that the detector and shot-hole line for in-line refraction control be continuously traversible and it need only be accessible at suitable intervals. Considerable adjustment of shot-hole and recorder locations is allowable ,and the surveying and laying of detector cables can be done along hand cut lines of sight. Rigorous adherence to straight detector lines, while most desirable, is not critical. In fact, it may be necessary in a new area to run a preliminary in-line refraction profile, located where accessibility is favourable and compromising locally on straightness, in order to ascertain refractor depths and the effectiveness of the tool. If has often been found that minor variations from the straight line can save much expenditure without maerially depreciating the results.

Economic Factors

The relative cost of seismic exploration in varying areas is a topic in itself, and no attempt will be made to detail this subject here. Generally speaking, a refraction crew requires about 40% more personnel and equipment than a reflection crew in the same area, but this will vary with the individual approach. Since drilling requirements are more severe and shot-hole locations are more restrictive in difficult terrain, the effort necessary for a reflection crew increases in relation to a refraction crew; hence, in such areas, the spread in cost between the two methods is reduced accordingly. Furthermore, the size and nature of the objective structures in foothills areas are such that, in most cases, a reconnaissance refraction pattern of control most effectively supplies the answers. A foothills area, in this way, often can be more effectively evaluated by considerably fewer miles of profile. The final outcome in such cases is a more co-

Figure 3


SD
R
SD
5 to 6 Miles
EQUIPMENT DEPLOYMENT - IN-LINE REFRACTION
SD
Shot - Hole Line
5 to 6 Miles
R
Detector Line
SD
Shot - Hole Line
EQUIPMENT DEPLOYMENT - BROADSIDE REFRACTION
Key
R
Recording Unit
SD
Shooting Unit and Drill Unit

herent over all picture of structural conditions at less cost to the operator than a normal reflection survey. It would also be interesting to compare the costs of properly exploring a plains project, using one mile and sometimes smaller grid, with the costs of exploring an equivalent foothills project, even with its operational disadvantages.

Future Foothills Seismic Exploration

Future seismic exploration in foothills areas will be improved both in the operational and the interpretive aspect. Some think that recent developments in larger capacity tracked equipment will be successful in solving the problem of hauling the necessarily heavy drills over widely varying types of difficult conditions, such as muskeg and steep foothills grades. Winter operations in the foothills will also be feasible, in spite of snow conditions, when such a vehicle has been tried and proved.

Regarding the technical and interpretive approach, there is no doubt that the impressive advances made in other modes of seismic exploration will be paralleled as the volume of experience in foothills areas grows. Better correlation between seismic and geological information, more velocity control, improved instrumentation and a more effective welding of the two seismic tools are avenues along which this progress can be made.

Acknowledgment

The author wishes to thank the British American Oil Co. Ltd. and United Trailer Co. Ltd. for equipment pictures, and the Texaco Exploration Co. for permission to publish copies of seismograms.

CORRECTED RECORD SECTIONS

ERNEST M. HALL, JR. (1)

Introduction

The problem of finding oil has always been a difficult one. No one technique or group of techniques has met all the requirements. Almost any idea that showed reasonable promise of locating oil and gas has been given a try. The ever increasing world demand for petroleum products and the high reward for success in the search has given birth to this situation.

Two professions, geology and geophysics, have proven themselves indispensable to an effective oil finding team. In the case of geology, this came about some twenty or more years ahead of geophysics. However, the growth of geophysics has been rapid, and to-day more than 1,000 crews are in use throughout the world.

At the outset, a feeling of rivalry and competition existed between the two groups, and there was little exchange of information and coordination between the two. However, since the early days much has been done to remedy this situation. The important part played in a successful exploration program by both geology and geophysics has commanded maximum co-operation between geologists and geophysicists. This not only requires personal respect and trust between the two groups but has also made desirable a better means of communicating information and conveying data. New methods presently available are helping to accomplish this, as well as the equally important problem of giving geophysicists more easily understood and more accurately presented data. These objectives are being accomplished through the use of corrected record sections.

Procedures

To make a subsurface map from reflection seismic data, it is necessary to recognize the reflected events. For many years the geophysicist has examined and compared the oscillographic recordings trace by trace for line-up of events on individual paper seismograms. The seismograms are analyzed record for record, and certain events are chosen for transferring and plotting on a cross section. This is a painstaking and uncertain process since the geophysicist is limited in the amount of information he is able to transfer, a decision must be made as to what events will be given significance. All other events and information are lost.

Governing the selections of horizons to be transferred is the geological problem of highest immediate interest. If later developments shift the centre of interest to different horizons or present new geological data, it is often necessary to go back and repeat the long and costly process of making a new map from the original paper seismograms. Even then, the same pitfalls of the original process can still be present. Consequently the use of corrected record sections enters a field where there is much room for improvement.

Record Sections

The technique of using record sections is not new. However, the widespread use of magnetic recording to store the original field data in a reproducible form has made the corrected record section practical.

A good record section should present all the data available in such a way that it is readily recognized and evaluated by geophysicists and geologists. It should eliminate the need for calculation and plotting and should remove as many distortions as possible while maintaining accuracy and maximum detail. All events should be portrayed in such a way that the quality, correlation, and significance of each can be readily interpreted.

(1) President, Electro-Tech Alberta Ltd.

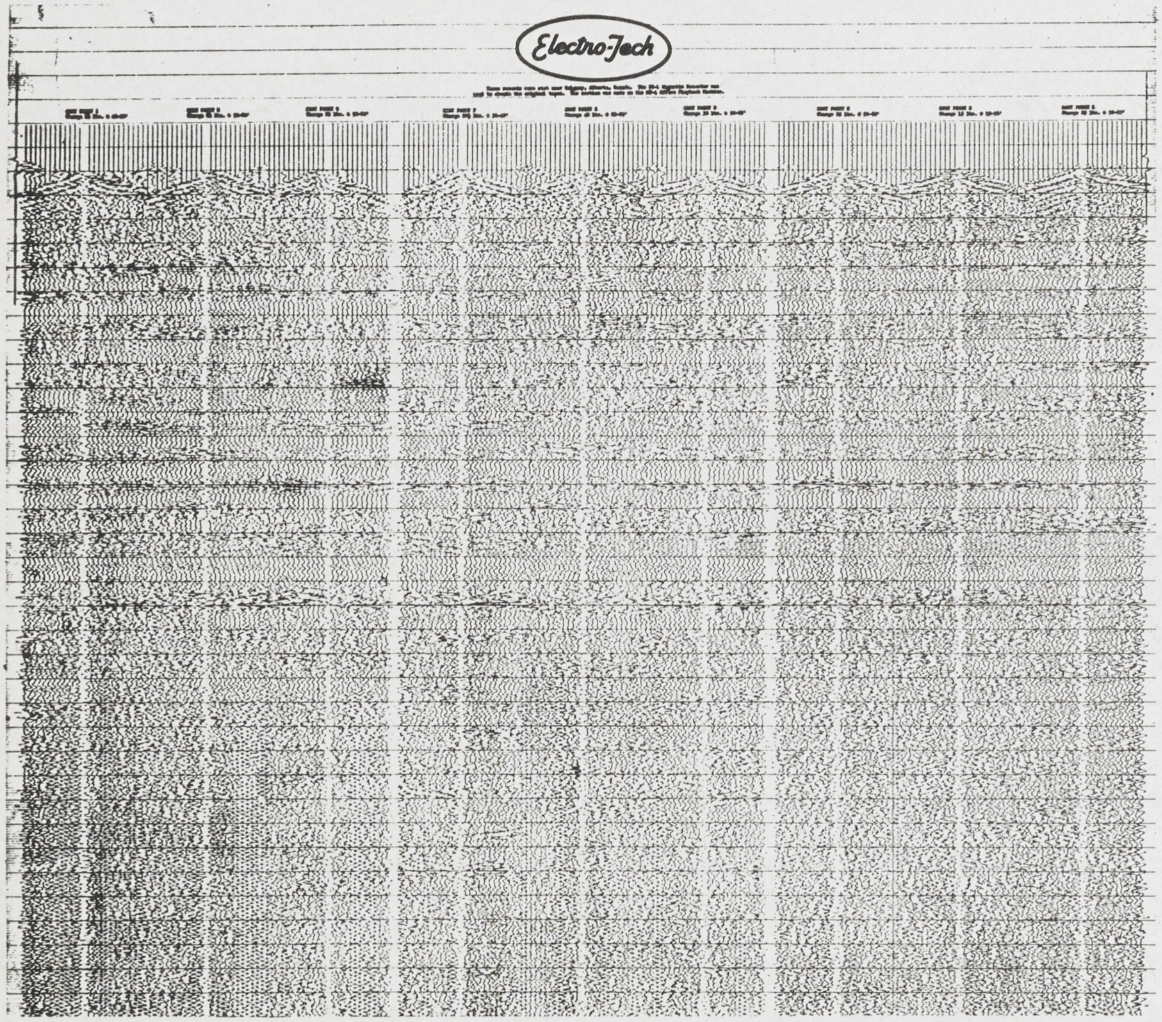


FIGURE 1

The nine records shown above were shot near Calgary. The tapes were recorded broad-band and played back through a 39-82 filter.

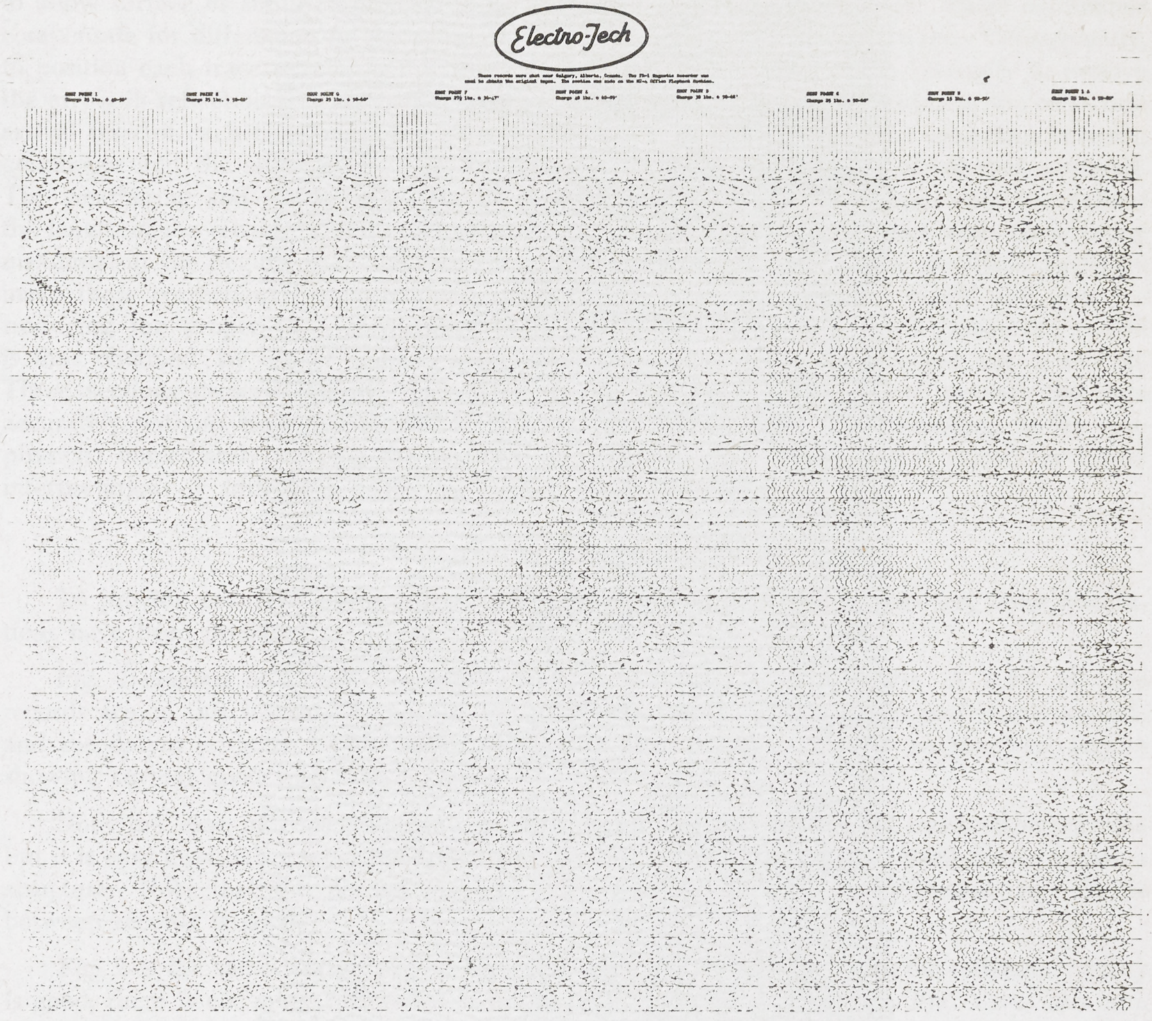


FIGURE 2

This is the same section as Fig. 1 except that a 28-56 filter was used during playback.

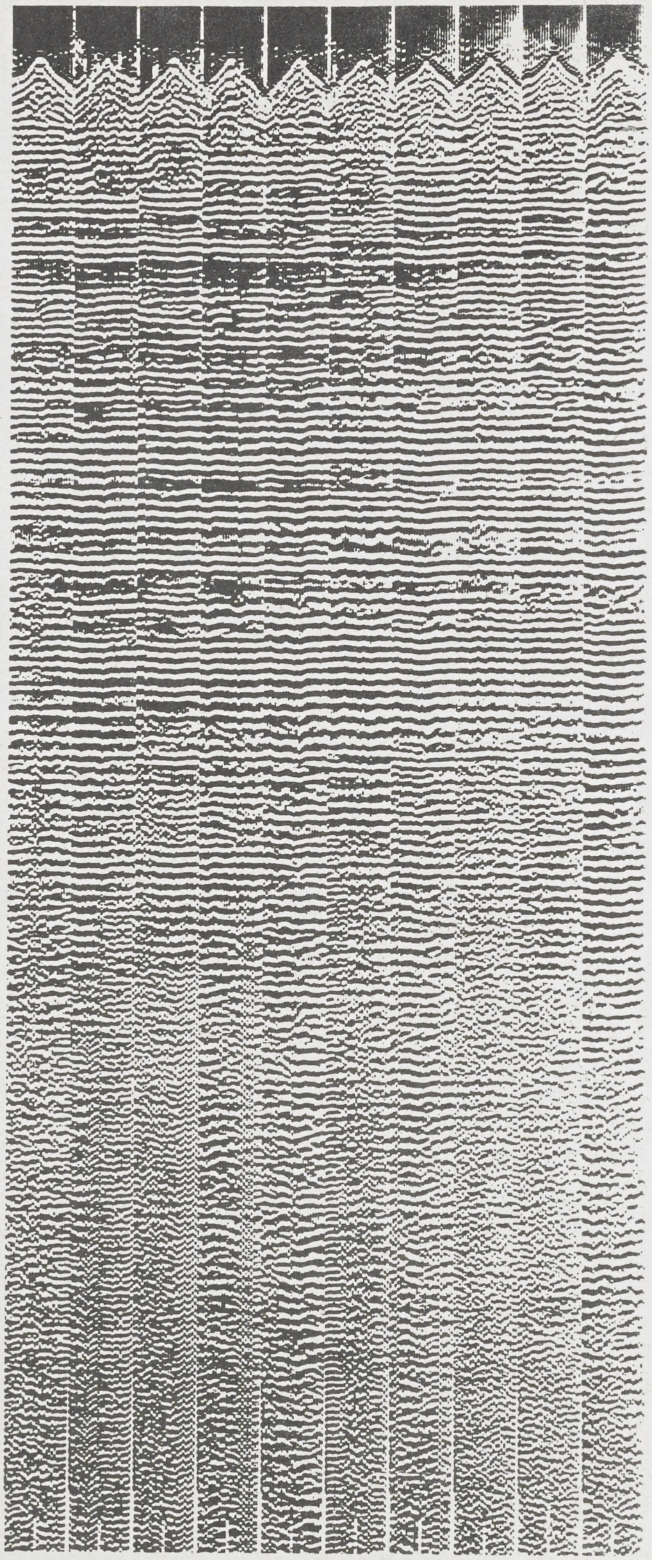


FIGURE 3

The same section is shown in variable density presentation. The reproduction here is poor. The original section showed much more shading and indicated relative amplitudes of events.

The procedure for doing this is as follows:-

The raw data is recorded on magnetic tape by the field crew with high fidelity in respect to raw time and frequency content. An uncorrected playback of the tape is made in the field to allow surface or static corrections to be calculated in the normal manner. These corrections compensate for differences in elevation and depth of weathering at each trace. Consequently, to position each trace of a reflecting horizon with respect to a datum it is necessary to remove the errors in reflection arrival times due to weathering and elevation. In addition, the reflection arrival time of each trace must be corrected for the errors introduced by the separation between geophones and the shot point. This correction is generally referred to as normal moveout. The weathering and elevation or "static" corrections are constant for a given trace throughout the length of the record. The normal moveout or "dynamic" correction varies with time, being maximum at the beginning of the record and decreasing with time. Office playback machines make these corrections by mechanically shifting the magnetic recording heads and thus introducing the proper time corrections, both "static" and "dynamic". A fully corrected record is thus obtained By use of a drum oscillograph, several records are combined into a section. These sections preserve all the information in the original recordings and present the data accurately without time distortions. In addition to the data being more revealing to the geophysicist immediately working the sections, maximum detail and accuracy is stored for future interpretations if additional geological data becomes available.

Examples of Record Sections

To provide examples of record sections and magnetic recording techniques, some illustrations have been prepared.

Fig. 1 consists of a fully corrected record section shot near Calgary. A total of nine records are on this section. A space is left at the shot point and between each three records and the datum is shown by the major timing line marked zero. This is an unmixed section showing several good reflecting horizons.

Note the ease of correlation and preservation of detail. There is not much structure here but it is easy to visualize what the appearance would be had the traverse been made across a structure. Note that the normal moveout correction has flattened the reflections and the tie between records is good.

Fig. 2 is the same section played back through a different filter. Since the reflection quality is good, there is not much difference in the general appearance. However, Fig. 1 was run on a higher frequency filter and breaks up the bands of reflections to a greater extent than Fig. 2. To make an isopach or correct the data to any horizon, it is simply necessary to insert the static corrections required to flatten that horizon across the section.

Fig. 3 consists of the same records shown in Fig. 1 except that a variable density presentation is used. Variable density has the advantage of being able to display large changes in signal level in a small track width for each channel. Thus, for a given area of cross section, more traces can be portrayed. Weak reflections can be brought to a recognizable amplitude without destroying the strong reflections. In addition, some geologists and geophysicists think that the visual aspects of the presentation lend themselves to a strong similarity to the actual geological sections of the earth. For the time being, it appears that both wiggly trace and variable density will be used to present sections.

In addition to providing a means of obtaining a corrected record section through time shifting, magnetic recording also lends itself to other valuable techniques in seismic instrumentation. The first two records of Fig. 4 show the effect of filtering. Both were played back from the same tape, the first through a high frequency filter and the second through a low frequency filter.

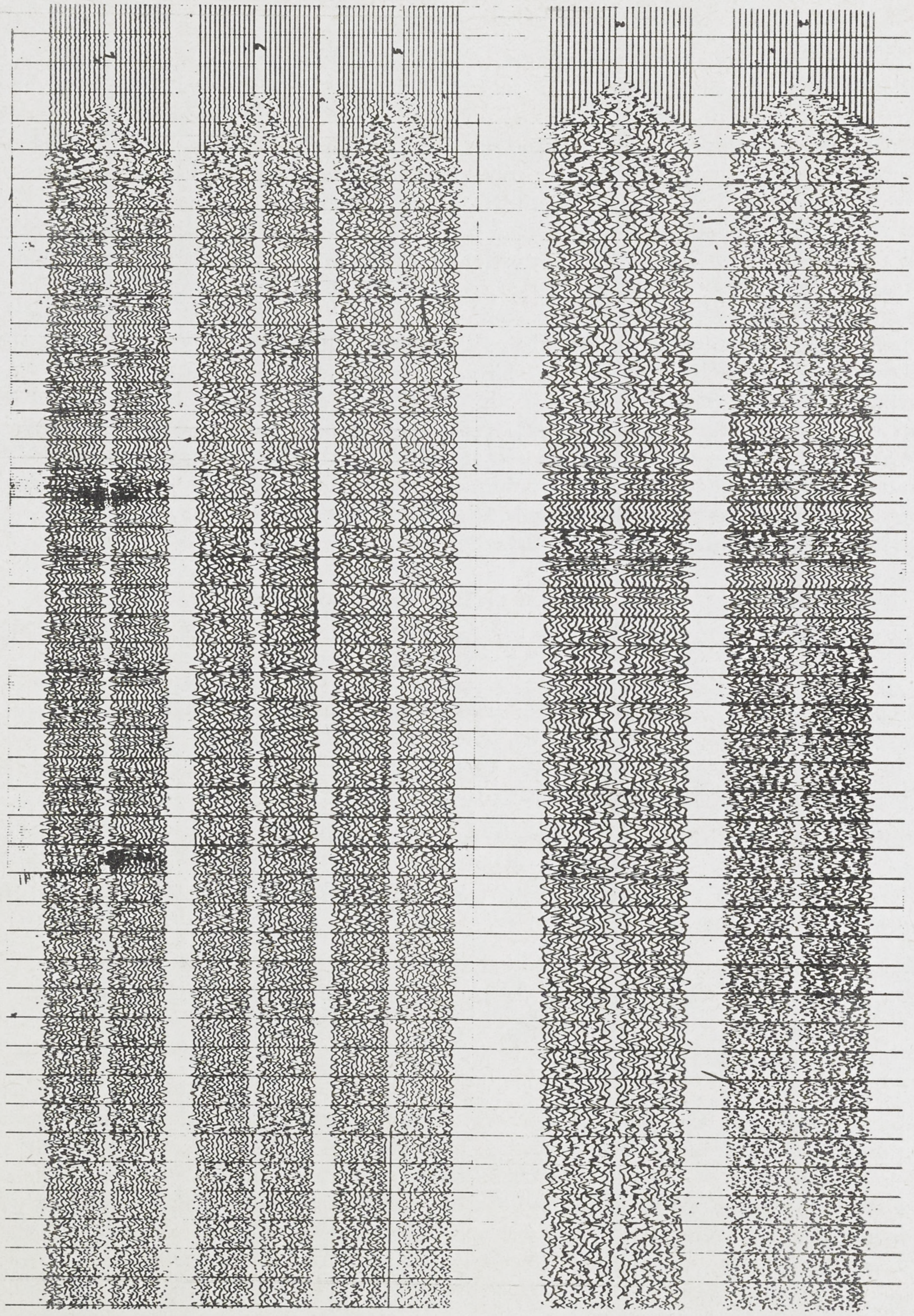


FIGURE 4

This illustrates the effect of filtering and mixing before and after corrections.

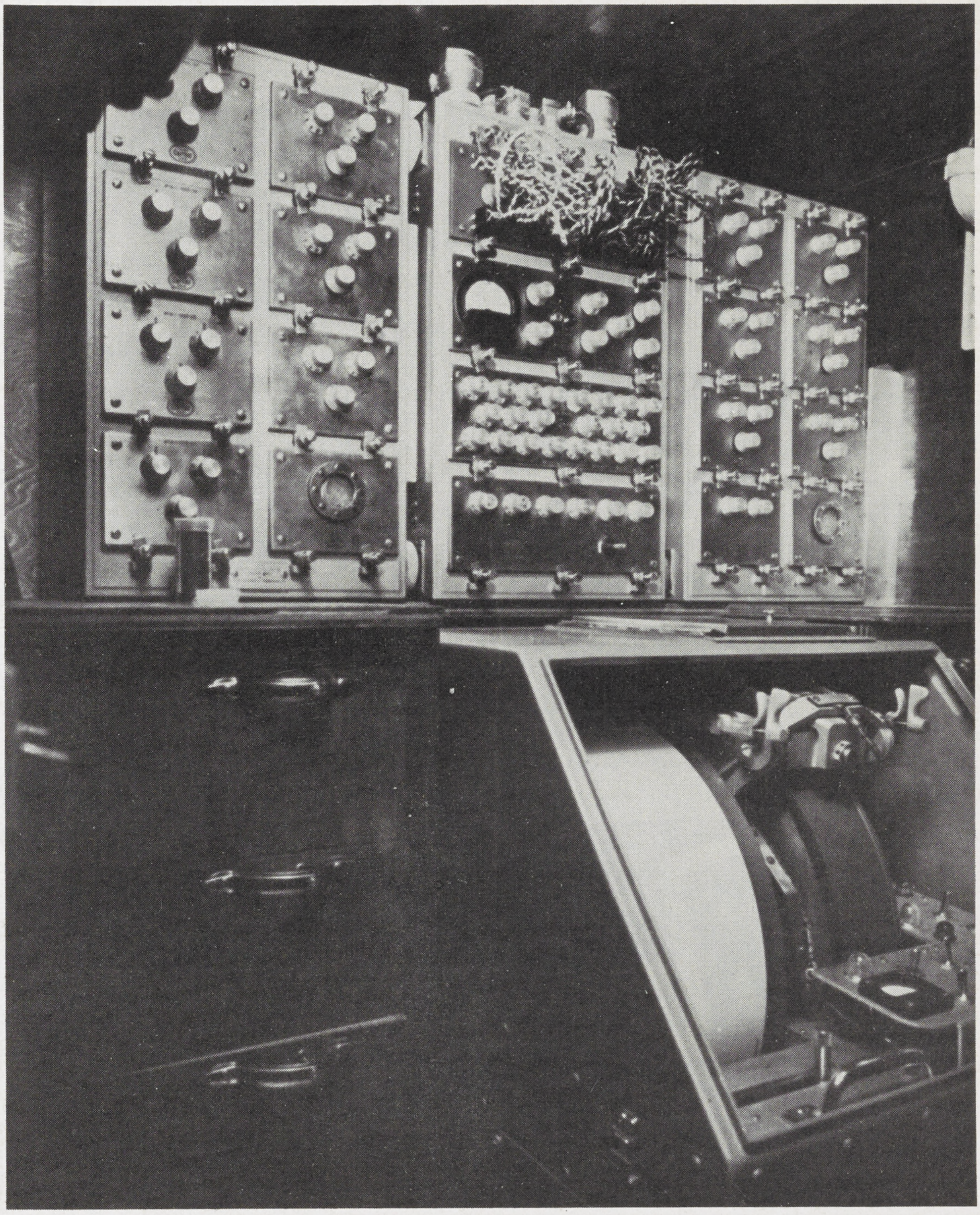


PLATE 1

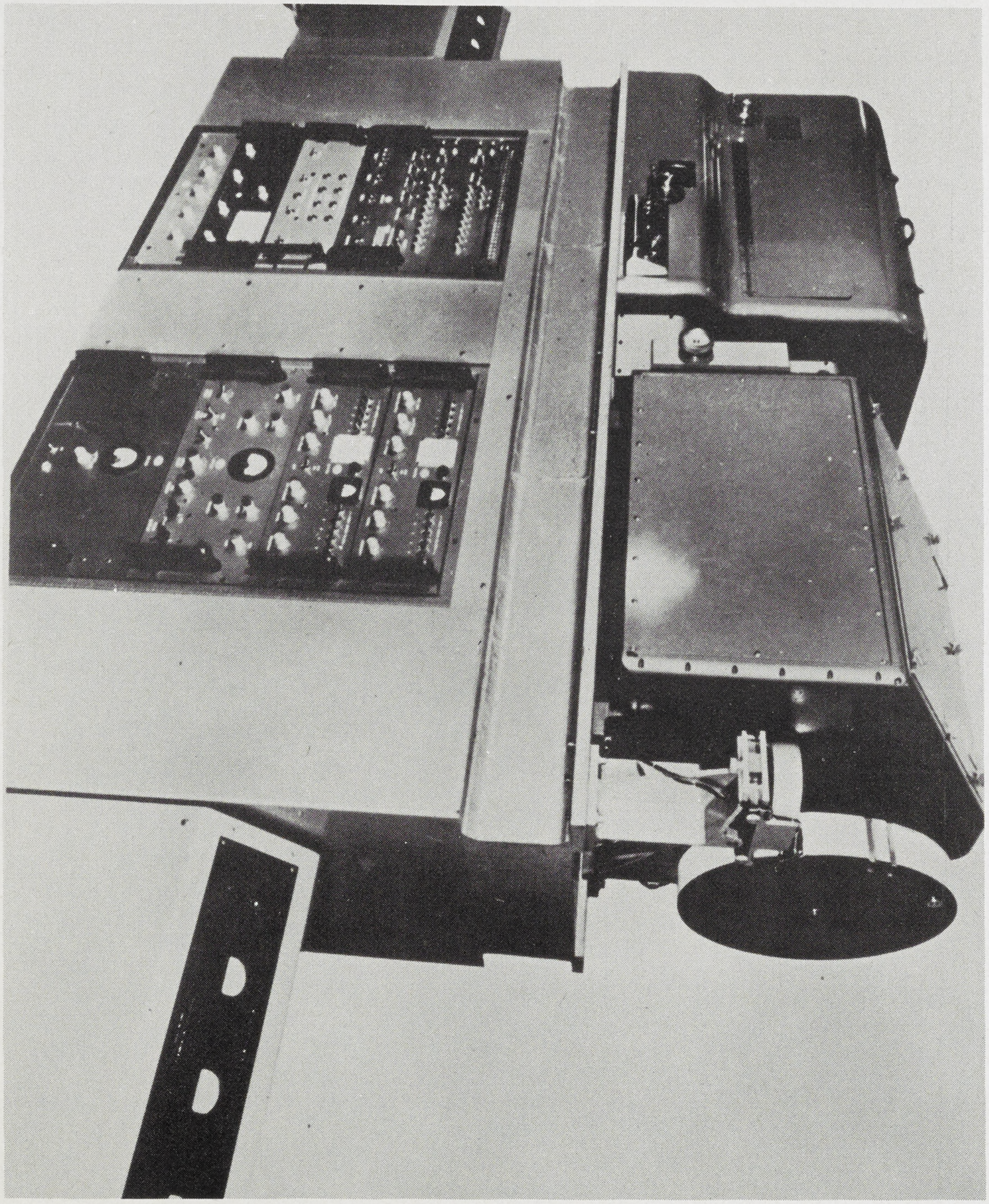


PLATE 2

Note that most of the reflections are more apparent on the high frequency filter whereas the one deep reflection is more apparent on the low. In some cases in the past, it has been necessary to shoot each hole twice, one for each filter, before the days of magnetic recording.

Another practice commonly used to improve record quality is mixing. Mixing of traces that have been time corrected is much more effective since reflected events should be in phase one trace with another. Fig. 4 illustrates this, Record # 3 is a raw field tape. Record # 4 is a mixed playback of # 3 without time corrections. There is little improvement in record quality. However Record # 5 is mixed after corrections. Here the improvement is easily apparent.

Equipment

The equipment used in obtaining these slides was developed by The Carter Oil Co. and manufactured under license by Electro Technical Labs. Plate 1 shows the field recorder The record amplifiers, modulators, demodulator and playback amplifier are housed in the upper case. The lower unit contains the down type tape transport and the dry process oscillograph. This set of equipment is shown through the courtesy of Nance Exploration and is shown installed in one of their instrument trucks.

The corrections and final sections are made in the office playback machine which is shown in Plate 2. The magnetic tapes from the field recorder are placed on the right hand drum and by transcribing to the memory drum located at the extreme left, time corrections are made by mechanically shifting the recording and reproducing heads. The sections are made on the drum oscillograph shown on the right. This plate is shown through the courtesy of Canadian Magnetic Reductions, whose playback machine is pictured.

Summary

In summary, equipment now available goes far toward utilizing to its fullest advantage the data contained in raw seismic records. Through the use of corrected record sections obtained with optimum filters, mix and automatic gain control, the geophysicist can make reliable interpretations. The data is preserved with all the detail originally recorded and with maximum accuracy and minimum distortions. It is in a form that is readily available for the geophysicist, geologist and exploration management, either for future reference or immediate consideration.

Acknowledgments

The writer wishes to express his appreciation to Nance Exploration and Canadian Magnetic Reductions for their assistance and co-operation in the preparation of this paper.

PHOTOGEOLOGY
BY
SPARTAN AIR SERVICES LIMITED

PHOTO INTERPRETATION STAFF

Introduction

With the advent of aerial photography, man at long last obtained the bird's eye view which he had desired from time immemorial. The first airphotos were taken from balloons soon after the development of practical photography by Daquerre in 1839. Today we stand on the verge of photography from space, as the rockets rise higher and higher.

In the field of geology, both in the purely scientific and economic aspects, the use of air photos has provided what is probably the best single tool yet devised. Air photos contain geological data ranging from the shape of the highest mountains, to the direction and velocity of water currents in rivers, lakes and seas. The last ten years has seen a threefold increase in the use of airphotos in geological work, and tacit acknowledgement of the importance of this work has been the coining of the words photogeology and photogeologist. We propose to cover briefly the methods and possibilities. of photogeology.

Photography

Vertical, black and white airphotos, taken in strips with 60% forward and 30% side lap are standard coverage today. The scale of the photos is usually a compromise between desirable image size and cost of obtaining the photography. It is also a compromise between the requirements of the various potential users, such as the topographic map makers, the foresters and the geologists. It is now generally accepted that a scale of 1:15,840 is one of the best for built up and readily accessible areas. Another scale much used in both accessible and non-accessible areas is 1:40,000. For remote areas, such as the Arctic and Northwest Territories, scales of 1:60,000 are used. The best scale for photogeology depends on the area and the prominence of the geological features. For example, Rocky Mountain Front Range or Appalachian structure is best interpreted from relatively small scale photos, because the rock and its fold structure is generally obvious. The extension of folds or faults is the important thing and using large scale photos entails a great deal of tedious piecing together of detail to form a whole structure, which can often be seen completely on the smaller scale. Conversely, minor structures, such as drag folds, cleavage and rhythmic banding in sedimentray rocks, is best shown in large scale photos ranging up to the continuous strip type, which can be at scales of 1:600. Unfortunately, to date most photography has been of the multipurpose type, and specific photography for geological purposes has been very limited. The ideal situation would be to have multi-purpose photography of the entire area of interest, with special areas covered at large scales for geological study. Color photography has been shown to be very superior to black and white, especially in the search for minerals. Its use has been limited to date by the extra cost, but this factor should be eliminated in the near future on the basis of comparable cost with methods which are not successful. It is a pleasure to report that this summer will see large scale experimentation in color air photography carried out in Western Canada.

Instruments

The basic tool of the airphoto interpreter is the stereoscope. The zone of overlap of two adjacent airphotos will yield a visual three-dimensional model of the ground surface, if the two photos are aligned with the flight line (i.e. the line joining the photo centres in the direction of flight) parallel to the visual plane in which the eyes operate simultaneously. It may consist of two lenses mounted in a frame, or a system of two or four mirrors. When the simul-

taneous viewing is accomplished, the land surface stands up like a model and has, indeed, the appearance of the ground as viewed by a giant whose height is that of the photo-aircraft and whose eyes are as far apart as the two positions in which the photos were taken. These factors result in an exaggeration of the vertical dimensions of the stereo model which is a great help in land form interpretation.

The small lens type of instrument is appropriately called a pocket stereoscope and it is possible to take the stereo model of the earth's surface into the field with one by taking the airphotos and lens stereoscope on field expeditions. The more elaborate mirror instruments are mainly of use in the office for viewing entire overlap zones. By adding magnifying binoculars, small detail can be studied and the useful range of the photography extended.

Photogeology

Photography is mainly applied geomorphology, or the interpretation of land forms. Land forms are the result of erosion and deposition by water, ice and wind, operating in various climates on rocks, consolidated and otherwise, having different resistances to erosion. In some areas the forms are mainly erosional, while in others mainly depositional. All areas show both, and one of the great problems is to distinguish between them. The ultimate aim of photogeology is to map the bed rock units and to work out their structure, if they are sedimentary or meta-sedimentary. It must be stressed that this is only part of the job of geological mapping — the geological age can only be determined on the ground and the physical characteristics in the laboratory. An esker or river terrace may be obviously composed of gravel, but only a lab check will tell if it is hard enough to use in road building or concrete work.

An example of obvious geomorphology is given in Plate 1, which is a stereo pair of an area in the Rocky Mountain Front Range. Massive beds of sedimentary rock, (limestones, conglomerates, and shales) can be seen with thinner and less massive beds interspersed among them. The rocks have been folded by lateral compression and subjected to erosion by water, ice and wind. The dissection of the beds by streams has notched them to leave residual wedge shaped sections, or flat irons. The dip of the beds is given by the direction of the notch point and this if often referred to as the "V" rule. Using this method, it is possible to work out the rock structure. A close study of the beds may reveal repetition and the occurrence of thrust faults may be deduced. In some cases, the actual fault zone can be seen in the ridges, but more often it is covered by debris and can only be inferred. However, using the photos the inferred position can be followed and places spotted where a ground search may reveal the fault in a stream, gully or cliff face.

The erosion of cirques and the rounding of valley contours by valley glaciers is another obvious feature. The depositional nature of some of the valley land forms is clearly seen and their lack of connection with the underlying bedrock is obvious. In most cases transverse valleys provide enough structural information to fill in areas masked by glacial debris.

Turning now to areas of moderate to low relief, it is necessary to distinguish between those which are the result of subdued structure with low dips, such as the Western Canada sedimentary basin, and those which are old erosion surfaces truncating fold structures even more intricate than the Rocky Mountains. Examples of the latter type are the Canadian Shield and part of the eastern seaboard.

In the case of the Western Basin area, two cases are cited. The Redwater Field is a Devonian reef in Devonian strata beneath an unconformity between Paleozoic and Mesozoic rocks. Nevertheless the general outline of the productive field shows clearly in airphotos as a change in tone. The southwest swing of the reef south of the river is clearly discernible. This case is unique in that the surface indications are so clear cut. The writers are not aware that any comprehensive check has been made of the entire airphoto coverage of the Alberta

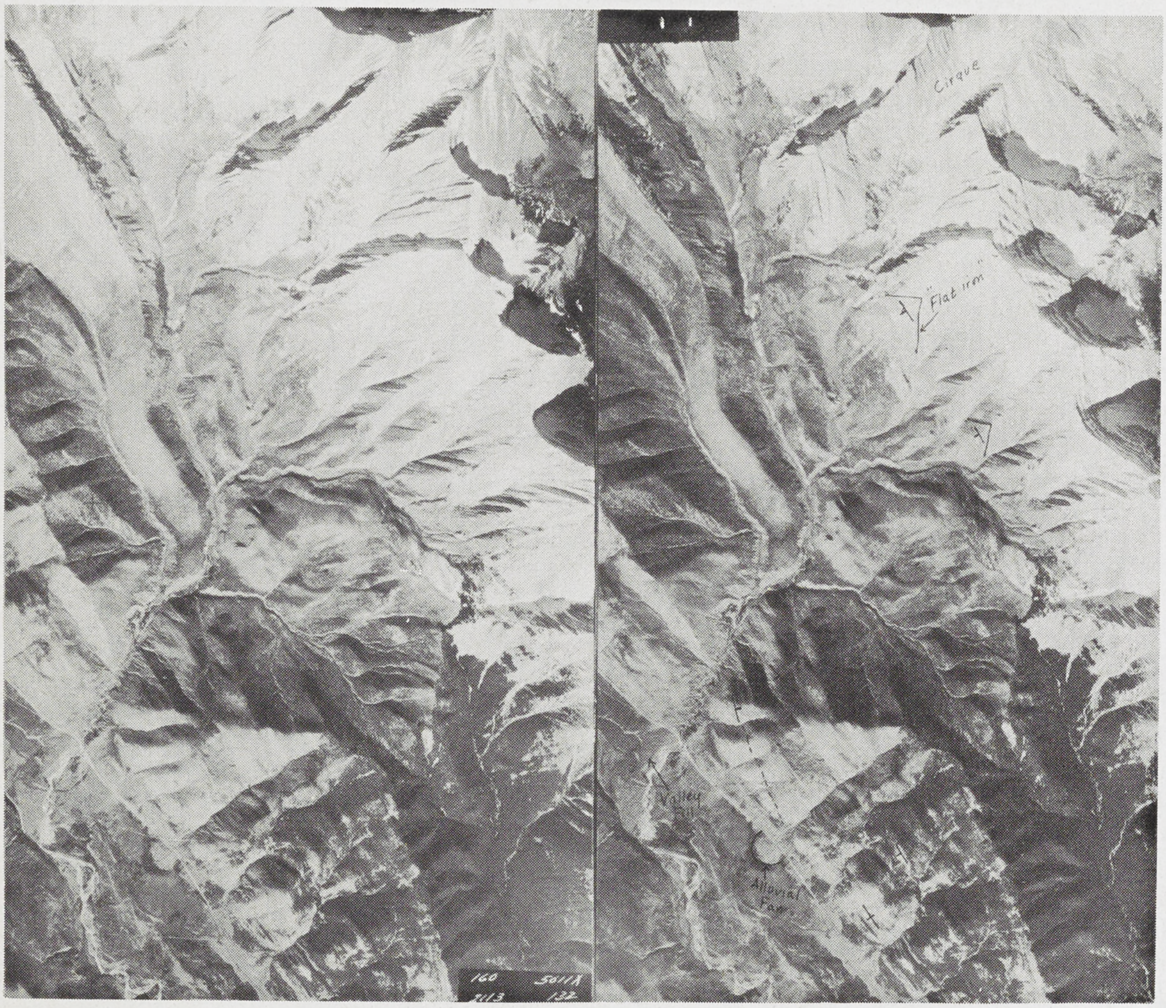


PLATE 1

Rocky Mountain Front Range area. Showing typical geomorphology of dissected sedimentary rocks. Original Scale 1: 40,000.

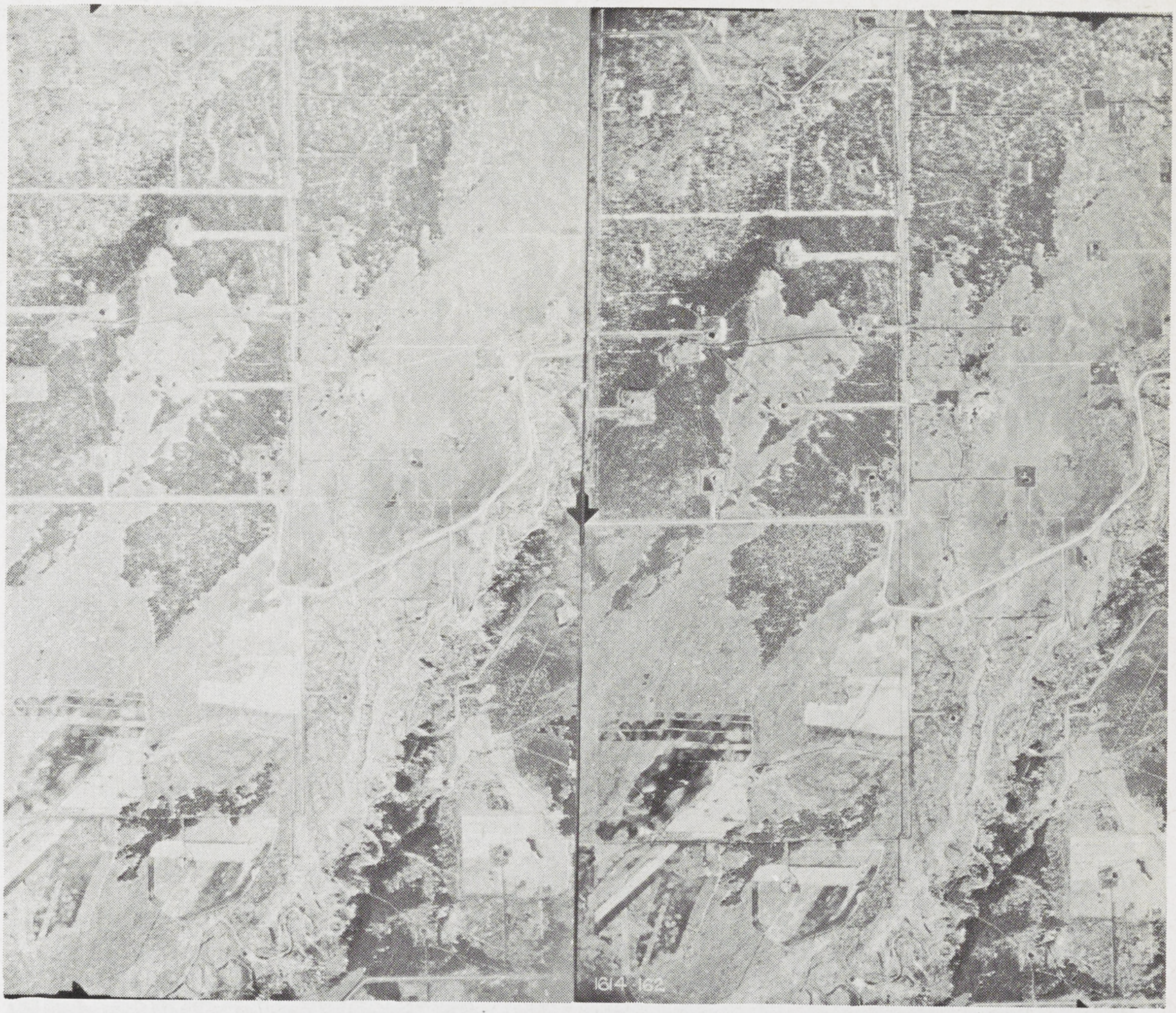


PLATE 2

Pembina Field, Alberta.
Original Scale 1: 24,000.

PLATE 3

Subsea Faulting – Pennsylvanian Sandstones and shales cut by group of faults which are concealed in shore section.

plains to check for similar occurrences but it has probably been done. The fact that reefs may show an actual surface reflection even through an unconformity is not so startling as might appear at first. Differential compaction over more dense or less compressible material should and does reflect in the overlying beds. In most cases, the results of this compaction, or draping, is discernible at the surface only in a pattern of fractures which can be picked out by the expert eye. The pattern may be significant to the knowing eye, but suffice it to say that it is probably more important statistically than pattern wise. The more fractures, the more differential compaction and the better chance for the presence of reefs, fault blocks, or other structural features which could hold oil or gas. Areas of stratigraphic thinning, pinch out, or truncation, will not, in all probability, yield significant information from airphotos. An example of the surface configuration of such an area is given in Plate 2 which is part of the Pembina Field. Here the oil trap is the pinchout of the Cardium sand.

Only a short discussion is necessary for Canadian Shield or truncated Applachian areas. In most cases glacial erosion has revealed sufficient bedrock surface to give a good section of the truncated structures. Details vary, but the extreme metamorphism, entailing confused folding and cross fracturing, is usually obvious. Care must be exercised that glacial features such as grooves, eskers and moraine deposits of various kinds, are not mistaken for bedrock features.

Before leaving the subject of photogeological interpretation, we wish to touch on an area which has not as yet received much attention. We refer to the coast lines and shallow water zones of our sea margins, large lakes and rivers. A study of these zones can reveal much and often can result in the projection of known geological sections for some distance beyond the beaches. In places features are revealed which are not visible on the adjacent land. An example is given in Plate 3 which reveals faulting in the sub-sea area. The faults shown are under twenty feet of water, and do not show in the adjacent shore section.

The configuration of the coast line may also reveal structural features which are almost impossible to map using ground methods. The known fact that anticlines tend to breach early and erode more rapidly than synclines is shown in shore lines in Eastern Canada. There, large bays are known on anticlinal axes and headlands on adjacent synclines. The same rule can be applied to scarps eroded on more resistant beds in inland districts.

To briefly summarize, examples have been cited of photogeological interpretation in mountainous country, flat lands and along sea coasts. The value of this technique, both in practical and scientific work, is so obvious that it needs little reiteration. However, the limitations must be stresssed and the point made that this work must be supplemented and completed by ground checks. It is not for the amateur, and even the experts must be wary of seeing things which are not there. Finally, with the proper background of field experience, extensive observation, and long experience of stereo study of photos, the photogeologist can approximate very closely to being master of all he surveys, stereoscopically; but he should keep his hob nails sharp.

Some Southern Alberta Oil and Gas Fields

SAVANNA CREEK GAS FIELD, ALBERTA

By

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W. J. HENNESSEY [2]
R. S. LAMON [3]

Introduction

The Savanna Creek gas field is located in southern Alberta, 25 miles southwest of the town of Turner Valley. The discovery well is situated 100 miles by road southwest of the city of Calgary, 50 miles north of the Crowsnest Pass, eight miles east of the continental divide, and three miles west of the mountain front. It lies therefore, well within the Rocky Mountains, rather than in the foothills, and is the only mountain gas field in Canada.

Maximum topographic relief in the area is about 3,000 feet. The average elevation and timberline are approximately coincident, at about 7,000 feet above sea level, with local relief commonly in excess of 1,500 feet. The highest point in the vicinity is the peak of Pasque Mountain, with an elevation of 8,358 feet. The mountains to the west, on the continental divide, rise to elevations of 9,000 to 10,000 feet.

About half the area is covered by conifers, but open grassy meadows with aspen groves can be seen in the main valleys. Those mountain tops carved in Palaeozoic rocks are generally bare of vegetation, excepting moss, lichen, the tougher grasses and mountain flowers. Upland mountain meadows exist in the glacial cirques. Plateau Mountain is, within the area, unique due to its flat top deeply indented by cirques. On it the mountain top gravels exhibit a polygonal appearance which is attributable to permafrost action. It is interesting to note that these gravels were once staked as placer gold claims.

The dominating feature of the region, Plateau Mountain, is a broad elongate dome, eroding in Palaeozoic sediments. It is nine miles long, three miles wide and 8,210 feet in elevation. Drilling, by the team of Phillips-Husky-Northern-Target, is concentrated on and around it. Considerable interest in the area is being shown by the industry, due to the location of the field and to its potential as a large gas reservoir. The wells drilled on top of Plateau Mountain are the highest in Canada, and among the highest in North America.

For most of the year, access to the region is limited to the Coleman-Kananaskis Forestry road, but a secondary dirt road, reaching the field from Nanton to the east, makes a spectacular approach through the foothills and over the first mountain range.

Previous Work

The discovery of a large reserve of gas at Savanna Creek has extended interest in exploration beyond the foothills and well into the mountains, where drilling has been shown to be feasible although, as discussed later, not without unusual problems. No detailed paper pertaining to this particular structure has yet been published. Previous summary accounts of the history and structural geology have been published by J. C. Scott (1953) and J. S. Irwin (1955). A cross-section by J. B. Webb and J. B. Spratt and another by T. A. Link, were published in the Bulletin of the A.A.P.G. The present paper does not pretend to be conclusive; it should be regarded more in the nature of a progress report, with an analysis of results to date.

(1) Husky Oil & Refining Ltd.
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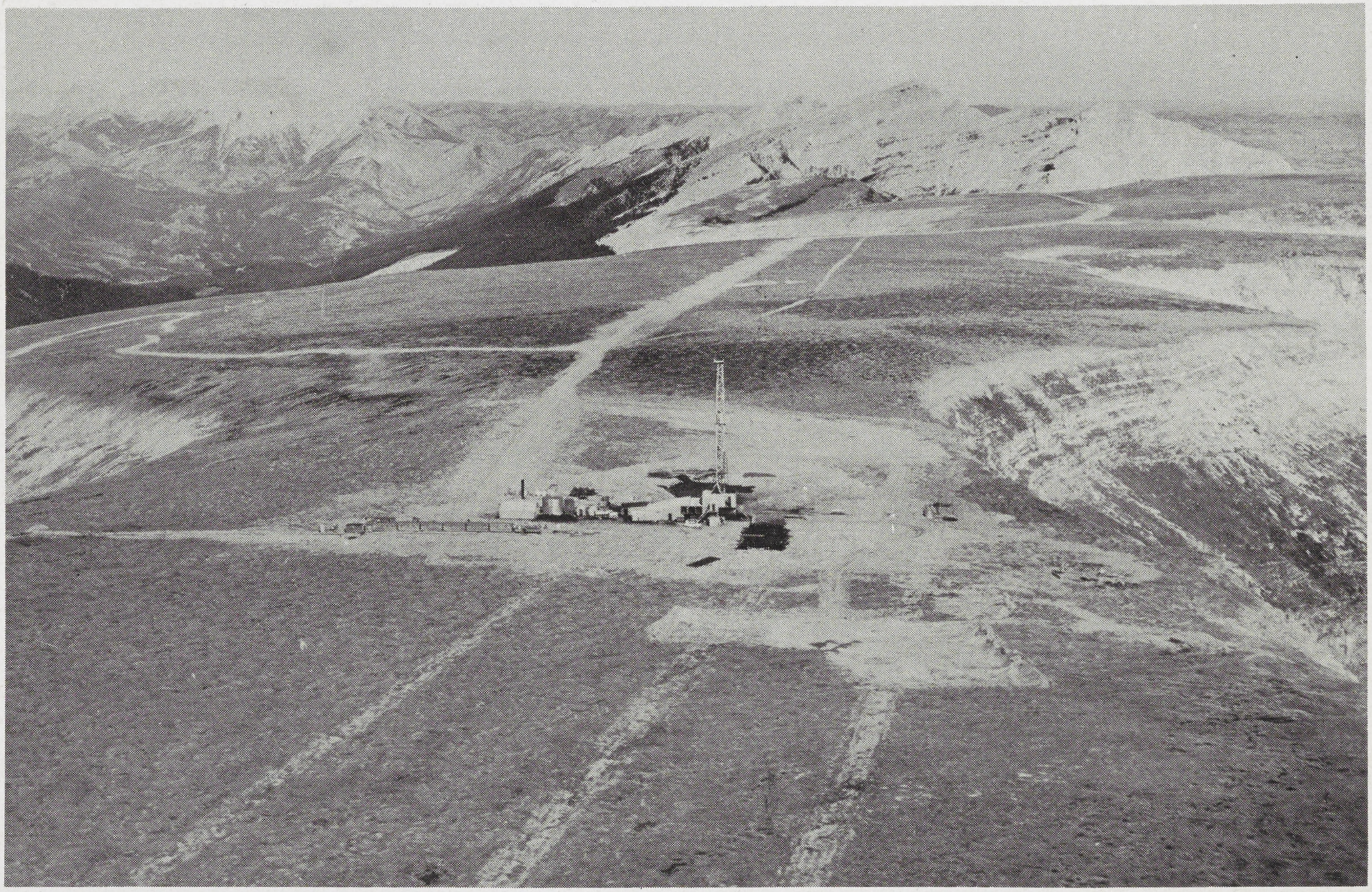


PLATE 1

1. Aerial view looking north along Plateau Mountain with Phillips-Husky-Northern-Target Savanna Creek 3A in the foreground.

The flat top of the mountain is readily apparent. On the right are the heads of cirques which deeply indent the side of the mountain. Near flat-lying beds of Rocky Mountain, underlain by Tunnel Mountain and Mount Head strata are clearly exposed in their walls. In the middle distance above the rig is Mount Burke; the west flank of this mountain is almost a dip slope at a horizon near the top of the Rundle. To the left of the photograph in the distance, is Mount Head.

PLATE 2

1. Aerial view looking west toward Savanna Creek 3A ,across Plateau Mountain.

In the foreground is the headwall of a cirque on the east side of Plateau Mountain. The upper cliff is located almost on the axis of the anticline, and is formed in Rocky Mountain and Tunnel Mountain beds. The contact with the underlying Mount Head formation. in which the lower cliff is cut, occurs just below the top of the upper scree slope. In the middle distance is Wilkinson Ridge formed in steeply west dipping Kootenay and Fernie beds. The prominent peaks in the background belong to the High Rock range, and locally represent the Continental Divide.

History of Exploration and Development

Interest in Savanna Creek as a potential petroleum producing area dates back to 1936. At that time, J. S. Irwin, at the request of W. D. McIlvride and associates, made a reconnaissance survey of the Plateau Mountain area. As a result of his investigations, Anglo Canadian Oil Company drilled their Savanna Creek 1 well.†

The well was spudded in 1939 in hope of obtaining Devonian production at shallow depth. It soon become evident, however, that a large fault had been penetrated very near the surface. The well was drilled to a total depth of 3,372 feet and abandoned near the base of the Blairmore formation.

Interest in the area waned until 1952, when Husky Oil & Refining Limited, associated with Northern Natural Gas Company and Target Petroleums Limited, drilled their Savanna Creek 1 well as a Mississippian test. A small but encouraging amount of gas was discovered in the upper limestones of the Rundle group, but the potential porous beds of the lower part of the Rundle were not present above a second major fault. The well was suspended in Kootenay beds, 348 feet beneath the fault, until August 1954 when the original group, joined by Phillips Petroleum Company as operator, resumed drilling and deepened to a third Mississippian Rundle block where a full section was penetrated. Gas was found in large volume, in the lower part, in beds partly equivalent to the Turner Valley formation.

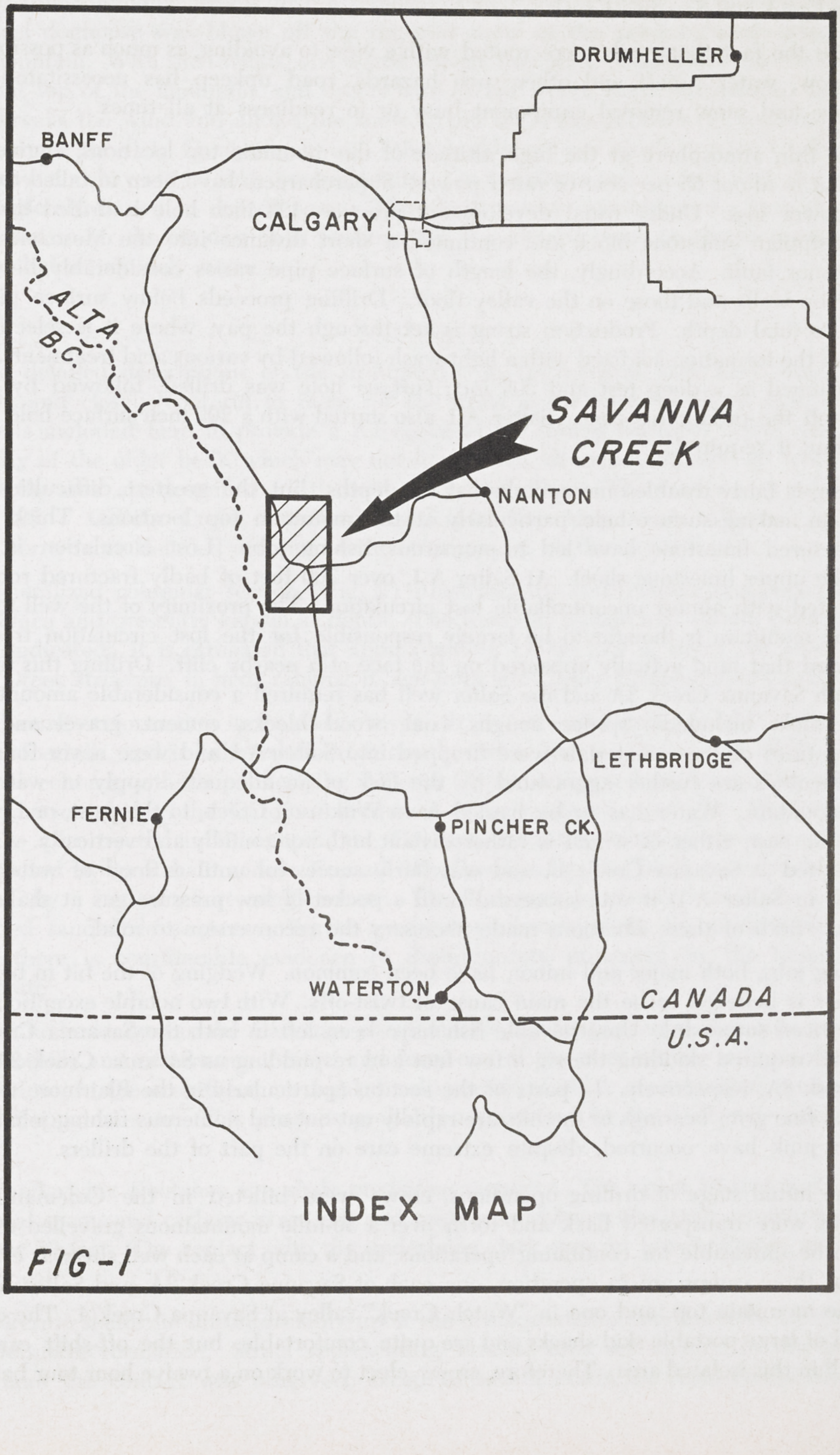
Following the discovery, a step-out well was drilled successfully one mile to the east. The third well, Savanna Creek 3A, spudded near the surface apex of the structure, and drilled through Devonian strata beneath the productive beds. Salter A-1, near the north end of Plateau Mountain and Savanna Creek 4 on the west flank, are also drilling at the time of writing; the latter to investigate the possibility of extending the field westward within the middle fault block, where an encouraging gas show was encountered in the No. 1 well. The present program calls for the continuing utilization of three rigs, and possibly a fourth, until development is carried to a point where marketable deliverability has been reached.

Drilling and Development Operations

During the present drilling program, which was initiated in 1952, the operators were fortunate in having available the recently constructed Coleman-Kananaskis Forestry Highway, which crosses the Savanna Creek structure. Geologically suitable locations for the first two holes were found along Dry Creek immediately adjacent to the highway. The discovery well was drilled only a few hundred feet from the initial well on the structure, Anglo Canadian Savanna Creek 1, drilled in 1936. At that time, no roads penetrated the area and the operators were faced with the difficult task of constructing a road over very difficult terrain through the foothills and over the front range. The present road to Nanton closely follows the Anglo access road. Usual access to the Savanna Creek area is by the Highwood River road, which leads from Longview to the junction with the Kananaskis Forestry road.

All wells drilled subsequent to Savanna Creek 2 have been staked at rather inaccessible locations. Road construction to these sites has called for considerable engineering ingenuity on the part of the operators. The most spectacular of these side roads, leading from the Kananaskis road, is the one that leads from Wilkinson Summit to the top of Plateau Mountain, and rises more than 1,700 feet in approximately five and one-half miles. This gives access to the two currently drilling wells on the mountain top and will eventually serve at least two additional locations, which have already been staked on this flat topped summit. Other roads,

† Where this well is mentioned, it shall be referred to as Anglo Canadian Savanna Creek 1. Other references to Savanna Creek 1 apply to the well drilled by Husky-Phillips-Northern-Target.



INDEX MAP

FIG-1

which have been built during the current operations, lead up the Livingstone River to a cirque at the eastern foot of Plateau Mountain; up Savanna Creek to a possible location on the south plunge of the structure; and up "Watch Creek" to the currently drilling Savanna Creek 4. Preparations are underway to construct a second mountain ascent to a proposed location lying between Dry Creek and Savanna Creek.

Despite the fact that roads were routed with a view to avoiding, as much as possible, slides, drifting snow, water runoff and other such hazards, road upkeep has necessitated keeping maintenance and snow removal equipment busy or in readiness at all times.

In the thin atmosphere at the high altitude of the mountain top locations, engine deliverability is cut to about 65 per cent of rated power. Superchargers have been installed to counteract this power loss. Under usual development practice, 12¼ inch hole is drilled through the first Mississippian limestone block and continued a short distance into the Mesozoics beneath the first major fault. Accordingly, the length of surface pipe varies considerably between the mountain top wells and those on the valley floor. Drilling proceeds below surface pipe in 8⅝ inch hole to total depth. Production string is set through the pay, where it is selectively perforated and the formation acidized with a light wash followed by various acid treatments. Savanna 3A was planned as a deep test and 20¼ inch surface hole was drilled, followed by 13¼ inch hole through the productive zone. Salter A 1 also started with a 20¼ inch surface hole to permit deep drilling if required.

Drilling is fairly troublesome and slow at all depths, but the greatest difficulties are encountered in making surface hole, particularly at the mountain top locations. Thick zones of highly fractured limestone have led to numerous fishing jobs. Lost circulation is common through the upper limestone sheet. At Salter A 1, over 700 feet of badly fractured rock had to be penetrated with almost uncontrollable lost circulation. The proximity of the well to the east face of the mountain is thought to be largely responsible for the lost circulation troubles. It was reported that mud actually appeared on the face of a nearby cliff. Drilling this upper section in both Savanna Creek 3A and the Salter well has required a considerable amount of mud, fiberseal (sacks included), spruce boughs, coal, wood blocks, cement, gravel and asphalt. Large quantities of these materials were dropped into Salter A 1 and were never found again. These difficulties are further aggravated by the lack of an adequate supply of water on the flat top mountain. Water has to be hauled from Wilkinson Creek, to the west, or Livingstone River, to the east, either of which is rather distant both horizontally and vertically. Air drilling was attempted at Savanna Creek 3A and was fairly successful until a flood of water was encountered; in Salter A 1, it was successful until a pocket of low pressure gas at shallow depth was found. Both of these situations made necessary the reconversion to mud.

Fishing jobs, both major and minor, have been common. Wedging of the bit in highly fractured zones is believed to be the main cause of twist-offs. With two notable exceptions, fishing jobs have been successful. Unretrievable fish have been left in both the Savanna Creek 2 and 3 wells and required skidding the rig a few feet and respudding as Savanna Creek 2A and Savanna Creek 3A, respectively. In parts of the section (particularly in the Blairmore which contains much fine grit) bearings in the bits are rapidly cut out and numerous fishing jobs for cones and other junk have occurred, despite extreme care on the part of the drillers.

In the initial stage of drilling operations, crews were billeted in the Coleman-Blairmore region and were transported back and forth over a 50-mile mountainous gravelled road. This proved to be unfeasible for continuing operations, and a camp at each well site was established. At present three camps are in operation, one each at Savanna Creek 3A, and Salter A 1, which are on the mountain top, and one in "Watch Creek" valley at Savanna Creek 4. The camps are composed of large portable skid shacks and are quite comfortable, but the off-shift camp life is rather dull in this isolated area. Therefore, crews elect to work on a twelve hour tour basis, which

enables them to take a full week in town following two weeks on duty.

Because of their exposed position on the mountain top, all equipment, including the camp houses, must be well secured and guyed. Wind velocities often reach 80 miles per hour or more and this commonly results in the removal of anything left loose. In one instance, at Salter A 1, a steel doghouse was blown off the rig, and some of the pre-fabs were actually carried off the mountain. With such winds, one would expect that snow would likewise be swept clear off the flat top of the mountain, and this is true except where some obstruction, man made or natural, breaks the wind and allows the snow to pile up in mountainous drifts around any object standing above the flat. Camp shacks and other buildings form excellent traps for the accumuation of snow and have to be dug out frequently. On occasions cars parked near the camp have been completely buried in drifted snow. Thunderstroms are something of a hazard in the summertime, but so far the rig derrick at Savanna 3A, the highest point on the mountain, has been struck by lightening only once.

Stratigraphy

Since detailed descriptions of the stratigraphy in the general area have been published previously and closely conform to those for the strata in the Savanna Creek area, only a brief summary is included here to provide a reference to the salient features. Some characteristics, particularly of the older beds, which may not have been described before or which may be unique to the area ,are described a little more fully than others. The reader may refer to G.S.C. Memoir 225, " Callum Creek, Langford Creek and Gap Map Areas, Alberta," by R. J. W. Douglas, for a more detailed account of the stratigraphy of the general area.

A generalized columnar section (Fig. 2) illustrates the stratigraphic sequence to be found at the surface and presently known at depth. The reservoir section and certain principal marker beds are indicated. It is estimated that approximately 14,000 feet of strata are involved in the Savanna Creek structure, in beds ranging in age from late Upper Cretaceous to Upper Devonian.

The youngest formation is the Belly River. It is not encountered in the wells, but crops out in the foothills, and is believed to lie at depth within the map-area. The Belly River is in transitional contact with the underlying Alberta Group, composed in descending order of the Wapiabi marine shales, the Cardium sandstone-shale sequence, and the Blackstone shales. Within the area treated in this paper, the Cardium formation contains three sandstone members separated by two shale zones. Beneath the Cardium lies the Blackstone formation marked at its base by a bed of chert conglomerate. The Blairmore formation, essentially a continental interbedded sand-shale sequence, lies in apparent conformity with the underlying Kootenay, although there is considerable evidence of disconformity presented by the basal Blairmore conglomerate.

These beds, known as the Cadomin conglomerate, are fairly general in distribution throughout the foothills and eastern mountains, and form one of the most readily recognizable markers in the section. In the area there are local developments of thick cross-bedded sandstones with little or no conglomerate. This phase is probably represented by the Dalhousie sand of Turner Valley.

The underlying Kootenay is a shale sandstone sequence. The upper 50 feet is characterized by thin coal seams and carbonaceous, salt and pepper sandstones; the latter extending downward for another 50 feet. The contact with the underlying dark grey to brown Fernie marine shales is gradational.

The Fernie shales lie unconformably upon the orthoquartzites and dolomitic siltstones of the Rocky Mountain formation. Strata representing Triassic time are missing in this area; in all places where the contact was observed, except at Savanna falls, the basal Fernie conglomerate

GENERALIZED COLUMNAR SECTION

SAVANNA CREEK AREA

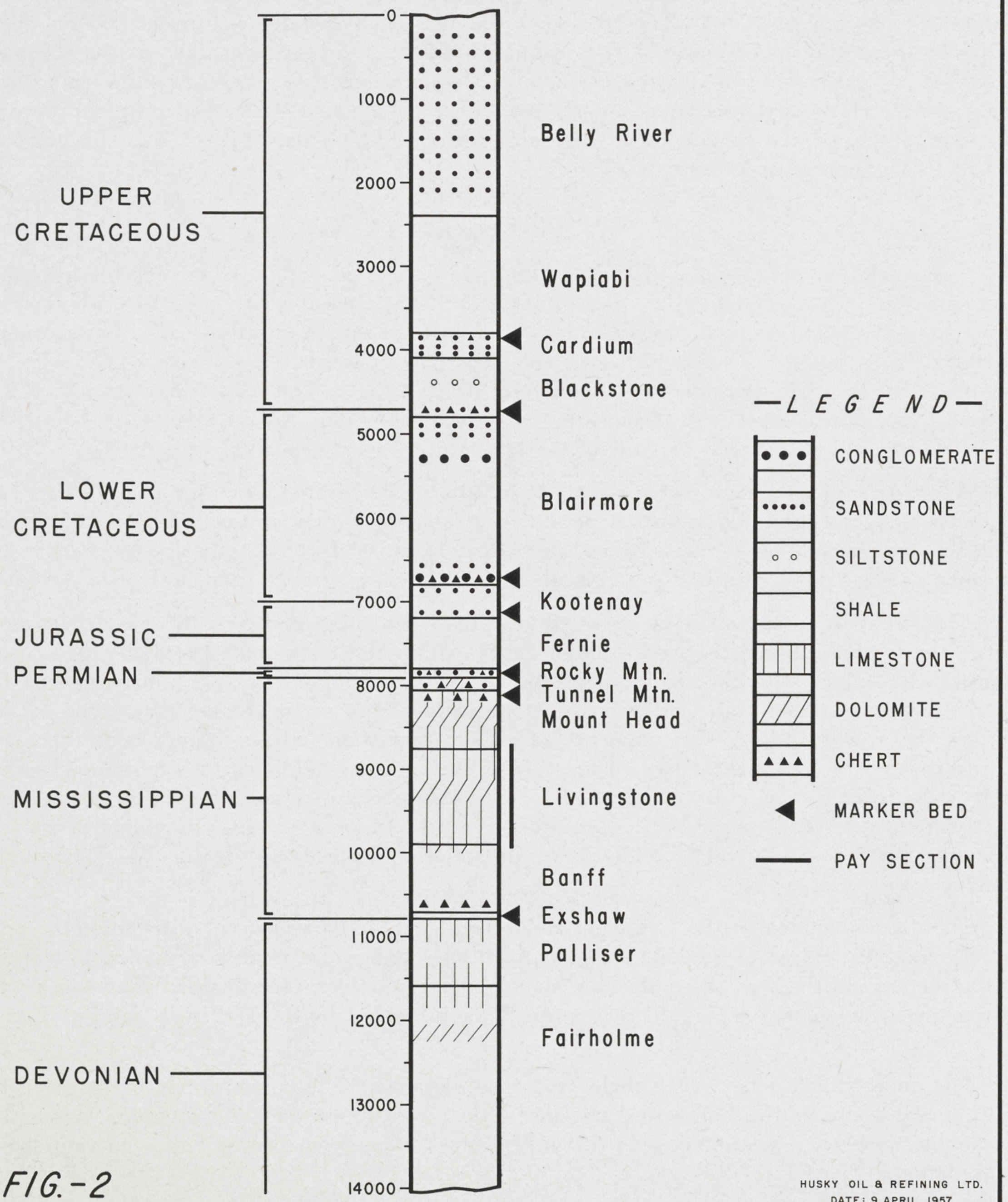
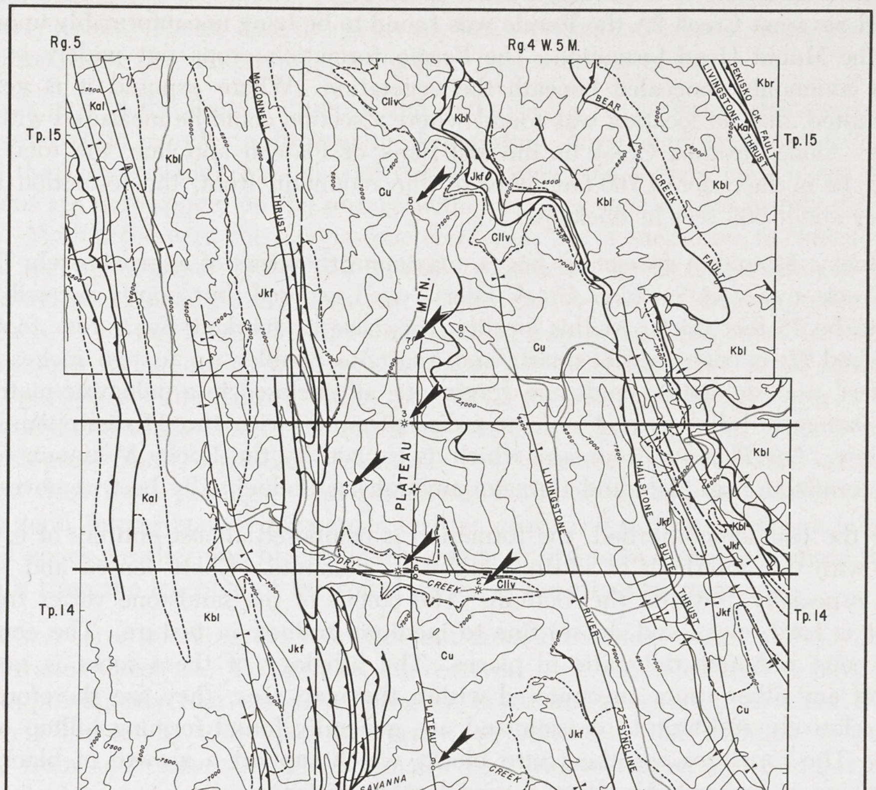


FIG.-2


Rg.5
Rg 4 W.5 M.
Tp.15
Tp.14
McCONNEL THRUST
PLATEAU MTN.
LIVINGSTONE RIVER
LIVINGSTONE THRUST
PEKISKO CK. FAULT
BEAR CREEK FAULT
HAILSTONE BUTTE THRUST
LIVINGSTONE SYNCLINE
DRY CREEK
SAVANNA CREEK
PLATEAU MTN. ANTICLINE
Kal
Kbl
Kbr
Jkf
Cu
Cllv
SAVANNA CREEK AREA
ALBERTA
SCALE
5000 FEET 0 1 MILE
LEGEND
GEOLOGICAL SYMBOLS
ANTICLINE
SYNCLINE
ANTICLINE—OVERTURNED
THRUST FAULT
CONTOUR—500 Ft. INT.
GEOLOGICAL BOUNDARY
WELL DESCRIPTION
1 H.N.T. Savanna Ck. I GAS WELL Discovery
2 P.H.N.T. " " 2A " "
3 P.H.N.T. " " 3A " Drilling
4 P.H.N.T. " " 11-30 Drilling
5 P.H.N.T. Salter A1 Drilling
6 A.-CAN. Sav. Ck. 1 Abandoned
7 P.H.N.T. Plateau 1 Location
8 H.N.T. Plateau 1 Abandoned
9 P.H.N.T. Sav. Ck. 3-8 Location
GEOLOGICAL FORMATIONS
Kbr Belly River
Kal Alta Group
UPPER CRETACEOUS
Kbl Blairmore
LOWER CRETACEOUS
Jkf Kootenay Fernie
JURASSIC
Cu Rocky Mtn. Tunnel Mtn. Mount Head
Cllv Livingstone
CARBONIFEROUS
HUSKY OIL & REFINING LTD.
DATE: 1 MAY 1957
FIG-3

is found resting unconformably upon the Rocky Mountain formation. The best exposure of the basal conglomerate is at the head waters of Plateau Creek. There it is six inches thick and is composed of sub-angular pebbles of black chert and grey sandstone, each up to ½ inch in diameter, enclosed in a matrix of dark grey, fine grained, dolomitic sandstone. In both Savanna Creek 1 and Savanna Creek 2A the Fernie was found to be lying unconformably upon the eroded surface of the Mount Head formation. The Fernie formation crops out widely over the map area but is commonly concealed beneath the vegetation. Where exposed it is generally contorted or faulted, and no location was found where a section could be measured with any degree of accuracy. Along Savanna Creek on the east flank of Plateau anticline, the total thickness is estimated to be in the order of 700 feet. East of tthe mountain front, the formation is thinner, a nd measures about 500 feet in thickness.

The Rocky Mountain formation has a maximum thickness of approximately 75 feet in the Savanna Creek area. At Savanna Creek falls, a well exposed, but poorly accessible section, is estimated to be 75 feet thick. At this locality, the base is marked by a two foot thick conglomeratic bed. It is composed of quartz and quartzite pebbles up to two inches in diameter, angular chert, and dolomitic sandstone fragments; all enclosed in a dolomitic matrix. It marks a definite change in lithology and at least a disconformity with the Mississippian beds immediately below. On Plateau Mountain which is capped by the Rocky Mountain formation, 28 feet of the formation is in place and a greater amount has undoubtedly been removed by erosion.

Above the conglomeratic bed, the formation is composed almost entirely of orthoquartzitic sandstone, with thin interbeds of siltstone and silty dolomite. Chert lenses and stringers are abundant, especially towards the bottom. The colour of the sandstone varies from off-white to pink. It is hard, clean and dense, fine to medium grained in texture. The cement is commonly siliceous, although dolomitic in places. The lithology of these rocks is quite different from that of any other strata encountered within the map area; they are therefore distinctive. They are relatively resistant to erosion and are generally found forming hilltop cappings and dip slopes. The formation weathers into blocks which support a growth of black and yellow lichens, making it recognizable from a considerable distance.

The Rocky Mountain formation is underlain by the Mississippian Rundle group composed of the Tunnel Mountain, Mount Head, and Livingstone formations. The unconformity between the Rocky Mountain and Tunnel Mountain represents a hiatus of at least all of Pennsylvanian time, since fossils of Permian age have been found near the base of the Rocky Mountain formation and others, approximately 50 feet below, in the underlying Tunnel Mountain represent Mississippian of Chester age.†

Correlations and naming of the rocks of the Rundle group in the vicinity of the Savanna Creek area, have been receiving considerable attention in the past few years, and a general agreement in this regard has not as yet been achieved, although it is understood that publications and papers now in preparation should do much to clarify the situation. In the course of the work at Savanna Creek, most of the units referred to by various authors, notably Douglas, have been recognized and mapped. For the purposes of this paper the rocks can most conveniently be referred to the three formations mentioned above.

The Tunnel Mountain formation in the Savanna Creek area, represents only the lowest member of the formation present at Storm Creek in the vicinity of Highwood Pass. It varies in thickness within the map area, but a typical section measures about 140 feet. The formation is composed of fine grained sandstone or siltstone, which is grey, dolomitic or calcareous. It is platy to very delicately cross-bedded, and weathers buff to light grey. Chert is common in

† The collections were made by the authors and the identification and age determination by Dr. Gilbert O. Raasch, formerly of Canadian Stratigraphic Services Ltd. and now consultant to Shell Oil Company.

the form of blebs and stringers, increasing in abundance toward the top of the formation.

The underlying Mount Head formation is approximately 725 feet thick in the Savanna area. It can be divided into three members which are generally composed of light brown to dark grey and black limestones and dolomites. Black calcareous shales and argillaceous limestones and dolomites are present. These, and the generally finely crystalline texture, distinguish the Mount Head formation from the underlying Livingstone formation or group.

The lower part of the Rundle group is referred to as the Livingstone formation in this paper. It has been referred to by other authors as the Livingstone group and in descending order subdivided into the Turner Valley, Shunda and Pekisko formations. Strata equivalent to the latter two formations are not exposed on the surface within the area, and are not readily distinguishable in the wells. Within the area the Livingstone formation has a measured thickness of approximately 1,160 feet. The upper 600 to 650 feet are considered to be equivalent to the Turner Valley formation, and constitute the main part of the gas reservoir; however, porosity extends upwards into beds of the Mount Head formation and downwards into zones in the lower part of the Livingstone formation, as well as into the upper 100 feet of the Banff formation. The Livingstone, particularly the Turner Valley portion ,is characterized by light grey to brown, fine to very coarsely crystalline limestone, much of which is very crinoidal. This is interbedded with brownish-grey, finely crystalline dolomite. The formation also contains anhydrite, chert stringers, and dark shale partings. The porosity of the reservoir beds is variable, ranging from negligible to good, intercrystalline to vugular. On the weathered surface, caves are fairly common and crinoidal zones weather into blocks which appear at first to be masses of crinoid stems. These features result from the leaching of the softer matrix of the crinoidal zones.

Thirty-seven cores ,totalling 771 feet were cut from the Mount Head and Livingstone formations in Savanna Creek 2A. From these, the reservoir rock was calculated to have an average porosity of approximately four percent. However, brecciated zones are present and it is, in many places, severely broken by long open fractures (see Plate 3). The addition to porosity and permeability from such intervals, which usually were broken further by coring, is hard or impossible to calculate, but must be considerable.

Rocks of the Livingstone formation pass gradationally downward into those of the Banff formation, which, like those of part of the overlying Livingstone formation, are not exposed at the surface. The formation consists of finely crystalline, brown and dark grey limestones; some finely crystalline, dark brown, dark grey and black dolomite, with much black calcareous shale. A stratigraphic thickness of approximately 690 feet was penetrated in Savanna Creek 1; the bottom of the formation was not reached. The entire Banff section was drilled in Savanna Creek 3A, where the thickness is estimated to be 670 feet. In this well, eleven feet of the Exshaw shales were penetrated beneath the Banff formation.

The nearest Devonian outcrop is on the contiental divide, eight miles to the west of the area. No detailed description of the stratigraphy of this area has been published. Savanna Creek 3A was drilled as a Devonian test and 2,152 feet (drilled) of beds of this age were encountered in what is believed to be of a normal sequence. The bottom was not reached. The well has just recently been completed and there has been little opportunity to study the section carefully. Since factors such as dip and faulting must be considered it would be unwise to attempt a precise description at this time, however, the Palliser section appears to consist mainly of light grey, very slightly porous limestone grading downward to dark grey, dolomitic limestone. The underlying Fairholme group contains much green and black shale interbedded with dark grey dolomite and dolomitic limestone.

Structure

The main structural features of the Savanna Creek map-area are the Livingstone River syn-

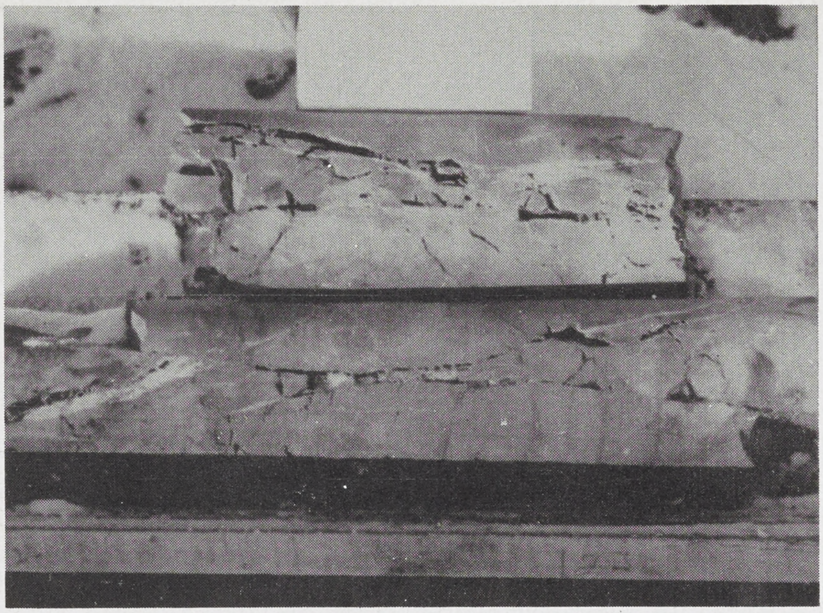


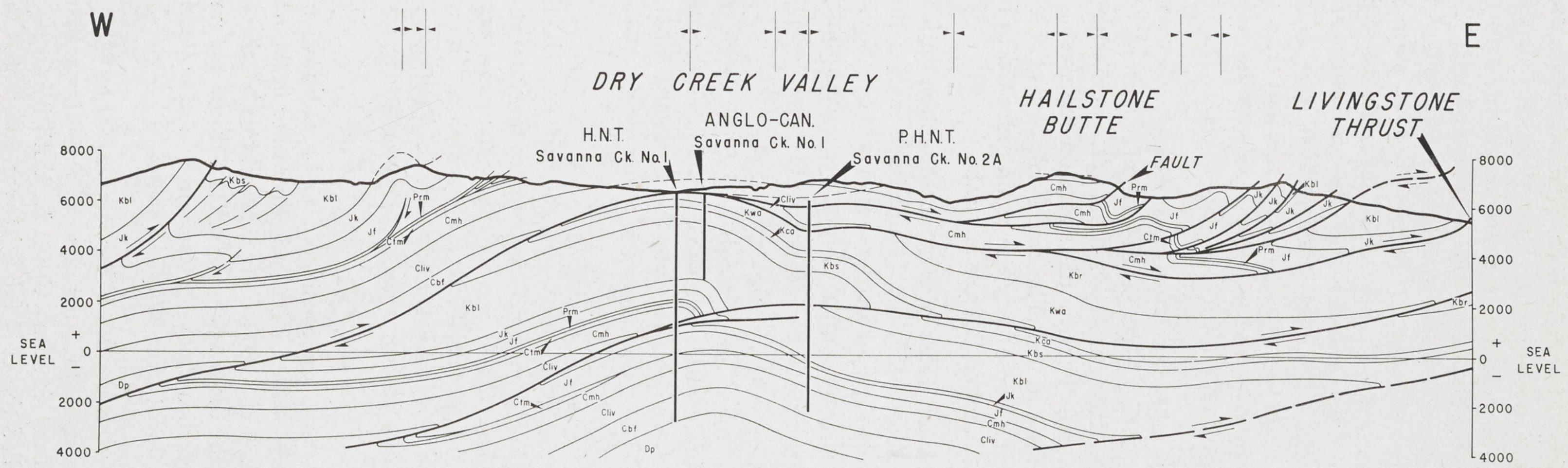
PLATE 3

(a) Steep to vertical fracturing in core from Savanna Creek 2A. Shown in the photograph are two lengths of limestone core with both open and healed fractures plainly visible. Diameter of core is 5¼ inches.

Photograph by courtesy of Imperial Oil Ltd., Calgary.

(b) Brecciated core from Livingstone formation, Savanna Creek 2A. Photograph of core showing brecciation of limestone, and resultant porosity. Length of section, approximately 15 inches.

Photograph by courtesy of Imperial Oil Ltd., Calgary.



STRUCTURE SECTION THROUGH SAVANNA CREEK NO. I

SCALE
5000 FEET 0 1 MILE

LEGEND

UPPER CRETACEOUS	Kbr	Belly River
	Kwa	Wapiabi
	Kca	Cardium
	Kbs	Blackstone
LOWER CRETACEOUS	Kbl	Blairmore
LOWER CRETACEOUS & / OR JURASSIC	Jk	Kootenay
JURASSIC & TRIASSIC	Jf	Fernie
PERMIAN	Prm	Rocky Mtn. Sandstone
MISSISSIPPIAN	Ctm	Tunnel Mountain
	Cmh	Mount Head
	Cliv	Livingstone
	Cbf	Banff
DEVONIAN	Dp	Palliser

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FIG.-4

cline and the Plateau Mountain anticline. These two features are well reflected in the topography, due in part to a protective capping of Rocky Mountain beds. The mountain front, specifically Hailstone Butte and Sentinel Peak, are in a west-dipping fault slice of Palaeozoic strata, mainly Rundle limestone. The traces of the faults along the western edge of the map-area are marked by elongate ridges in Mesozoic sediments. The map (Fig. 3) covers an area which includes the north end of the Livingstone Range, and en echelon to it, the south end of the Highwood Range. The mountain front in general trends about 20 degrees west of north but at Plateau Mountain it cuts sharply across the structure. Plateau Mountain anticline trends almost due north, and crosses the mountain front into the foothills. On the surface, near its culmination, this fold is expressed in Rundle and Rocky Mountain strata, which have at Dry Creek, an exposed width of three miles. Palaeozoic strata are exposed along the fold for a distance of eight miles, but the axis can be followed in Jurassic and younger sediments for a considerable distance beyond the map-area to the north and south.

A good cross-section of the surface fold is readily visible in Dry Creek Valley, an east-west trending U-shaped canyon incised completely through that part of the Rundle section lying above the Livingstone fault at this locality (Fig. 4). Unfortunately, the fault, overriding Alberta shales, is concealed by scree in the valley bottom. The Rundle strata on the west flank of the fold dip at an average angle of 22 degrees at the surface. The east flank dips at a lesser angle, about 10 degrees, into the Livingstone syncline. These beds rise again eastward to form Hailstone Butte, where they override contorted and faulted Mesozoic strata.

An imbricate structure has developed upon the west flank of Plateau Mountain anticline; the faults are small, and at the surface they repeat slices of Rocky Mountain formation thrust upon Fernie shale. The traces of these faults are well exposed in the rimrock above Savanna Creek and all give indication of merging into bedding-plane slippage along the unconformity at the base of the Rocky Mountain formation. These small faults are probably the local manifestation of the McConnell thrust.

To the west, toward the edge of the map-area, there are a number of fairly large, relatively steep thrusts. At the surface these faults lie entirely within Mesozoic strata in what appears to be a near bedding plane attitude. They are not believed to penetrate the westward extension of the surface limestone sheet within the map-area. They do, however, effectively mask the structure at depth.

East of the mountain front, within the foothills, several faults reach the surface. The most westerly of these is the Hailstone Butte thrust, marking the boundary between mountains and foothills. It rises out of a synclinal fold just east of Dry Creek and its throw increases rapidly northward. North of Salter Creek it forms part of the Mount Burke fault complex. The other faults to the east are smaller, and at the surface are confined entirely within Kootenay and Blairmore beds. Some are quite obviously folded, and may be seen in cross-section in certain ravines east of Hailstone Butte.

All these faults, including the Hailtsone Butte fault, are considered to be imbrications of the underlying Livingstone thrust. The surface trace of the Livingstone thrust lies in the northeast corner of the map-area where the throw amounts to 3,000 feet. The throw on the fault is progressively greater to the south. Due east of the discovery well, it has a throw amounting to about 7,000 feet. Drilling has shown that it underlies Plateau Mountain in a near bedding-plane attitude where Livingstone beds have been thrust over Wapiabi shales.

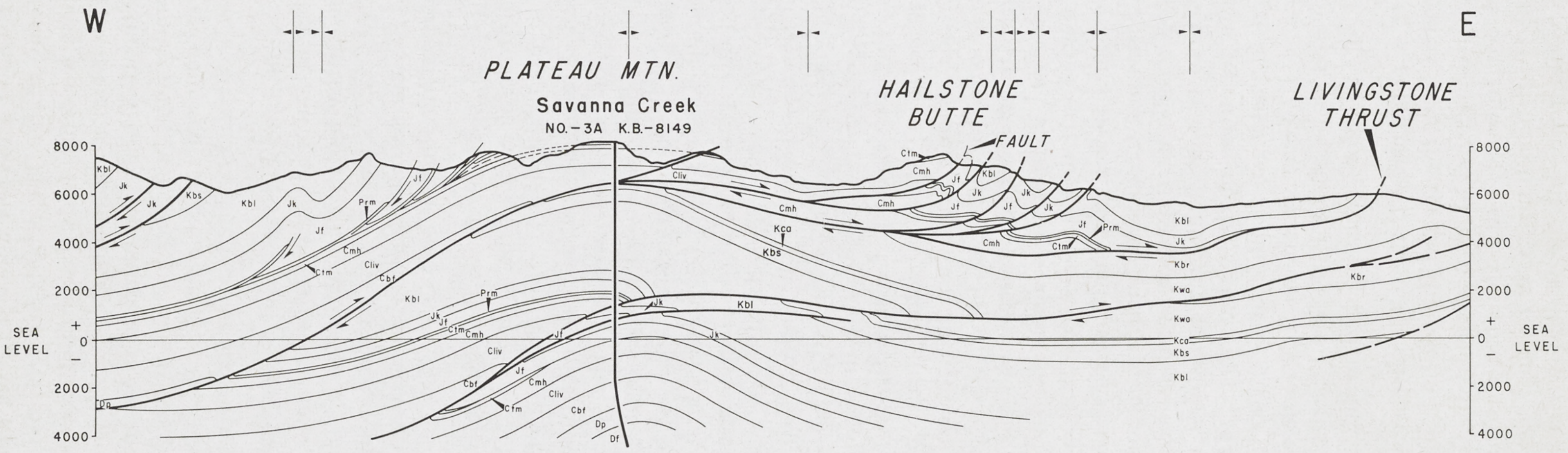
A second large thrust fault has been encountered at depth. It lies from 3,000 to 6,000 feet below the Livingstone fault and has repeated 900 to 2,000 feet of strata. This fault was first encountered in the discovery well, Husky-Northern-Target Savanna Creek 1. Until it can be correlated with known faults, for convenience, it is called the H-N fault. It was intersected in the

No. 1 well at 1,133 feet above sea level where Rundle beds of the second fault block lie upon Kootenay strata. These beds are repeated, immediately beneath, by a subsidiary fault. It was in these Kootenay beds that drilling was temporarily halted. The combined throw across the H-N fault and its branch is about 2,000 feet. When the No. 2A well was drilled, one mile to the east, the H-N fault was found to occur much higher in the section, lying entirely within the Blairmore formation. Its elevation at this point is 1,788 feet and its throw 900 feet. The H-N fault was encountered at an elevation of 1,273 feet, and its subsidiary at 689 feet in Savanna Creek 3A well. (Fig. 5). Their combined throw is about 1,800 feet.

At the time Figures 4 and 5 were being prepared for this paper, Savanna Creek 3A was drilling in Devonian strata (this is shown in Fig. 5), that further faulting was anticipated is evidenced by tentative faults drawn on both cross sections. The well has since reached a total depth of 13,798 feet, having passed through another major fault from Devonian to Rundle beds.. Time has not permitted a full appraisal of the newly acquired data and its incorporation into the accompanying illustrations.

The cross-section drawn through the wells on Dry Creek (Fig. 4) discloses a similarity in the attitude of each of the fault slices. The structure may be regarded as a simple anticline in which these fault blocks are folded together. In detail, considerable complexity is added by structural features, such as drag, bifurcation, increase and decrease of throw, associated with the faulting (of earlier occurrence). The No. 1 well spudded in scree which fills a window through the surface limestone fault block. Upon penetrating some 100 feet of gravel, the drill entered Wapiabi shales below the fault followed by a normal sequence down to the Rundle Mount Head formation. Then, as described above, a fault to Kootenay beds was encounteerd. Below, drilling proceeded through another normal section to the base of the Banff, which was reached at total depth. When No. 2A was drilled, the situation was found to be somewhat different. The surface limestone sheet is thought to be repeated since the Livingstone fault was not encountered until a depth of 1,452 feet was reached. The fault causing the repetition of the surface slice is placed at 417 feet, drilling depth. It is interpreted as being the Hailstone Butte fault, branching off the Livingstone thrust just east of the No. 1 well. The strata lying beneath the Hailstone Butte thrust and above the Livingstone thrust are limestones, dark-grey to black in colour, very argillaceous, grading downward to light grey limestone. There was, at the time of drilling, some discussion as to the possibility of these beds being of Banff age lying conformably beneath Rundle strata. This possibility is thought to provide the least likely explanation of the facts in consideration of the data available, and the known habit of faulting elsewhere in the front ranges and foothills. It would necessitate that the Livingstone thrust cut upwards through Banff west of Savanna Creek 1, and then down section again through the same beds between Savanna Creek 1 and Savanna Creek 2A. Such a situation is not known to exist anywhere in the Rocky Mountains. Considering the black argillaceous character of the Mount Head sequence and its downward gradation to light grey limestone, the beds between the two faults are interpreted as being a repetition of the surface rocks. This repetition of strata along the Hailstone Butte fault caused the Livingstone fault to lie 1,100 feet lower than was originally anticipated from surface evidence. However, when the H-N fault was intersected in Savanna Creek 2A, the throw was discovered to be about 1,100 feet less than in the No. 1 well. The reservoir section beneath the fault, therefore, was reached at the depthexpected.

It is noteworthy that, in the discovery well, a small, but encouraging, amount of gas was recovered from the second Rundle fault block. As indicated in Figures 4 and 5, the Livingstone strata in the second block was cut by the H-N fault to the west of Savanna Creek 1 and Savanna Creek 3A. In No. 1, a drill stem test was run in this fault block covering part of the usually dense Mount Head limestones. Gas reached the surface in four minutes at a rate of 520 McF/d. This show could represent the faulted wedge-out of a much larger reservoir to the west, where porous beds of the Livingstone formation (the present reservoir) can be expected above the H-N



STRUCTURE SECTION THROUGH SAVANNA CREEK NO. 3A

SCALE

5000 FEET 0 1 MILE

LEGEND

UPPER CRETACEOUS
- Kbr Belly River
- Kwa Wapiabi
- Kca Cardium
- Kbs Blackstone

LOWER CRETACEOUS
- Kbl Blairmore

LOWER CRETACEOUS a/OR JURASSIC
- Jk Kootenay

JURASSIC & TRIASSIC
- Jf Fernie

PERMIAN
- Prm Rocky Mtn. Sandstone

MISSISSIPPIAN
- Ctm Tunnel Mountain
- Cmh Mount Head
- Cliv Livingstone
- Cbf Banff

DEVONIAN
- Dp Palliser
- Df Fairholme

HUSKY OIL & REFINING LIMITED
DATE : 27 MARCH 1957

FIG.-5

fault. An ideal fault trap situation is present inasmuch as the porous zones are faulted against the Fernie and Kootenay shales. A well, Savanna Creek 4, is currently drilling to explore for production in this potential trap.

Perusal of Figure 5 showing a cross-section through Savanna Creek 3A, will make apparent the structural similarity between Savanna Creek 3A and Savanna Creek 1. The same fault blocks were encountered, and the reservoir was reached in No. 3A at approximately the same elevation as in No. 1. The most obvious difference is that of elevation and the surface rocks encountered. The No. 3A well started some 1,800 feet higher and drilled most of the Rundle group before reaching the structural position of No. 1. The second or middle Rundle slice was also encountered in No. 3A. This section was not tested but log data gives indiciation of gas zones similar to well No. 1.

It is evident that there are at least three major thrust faults directly involved in the structure. The upper, the Livingstone thrust, has the greatest throw and apparent displacement. In the immediate vicinity of Savanna Creek 1, it has a throw of 7,000 feet, and a horizontal displacement estimated at eight miles. An interesting feature of this and many other faults of the same type is the almost complete absence of contortion in the strata quite close to the fault plane. In Dry Creek valley no evidence whatever exists to indicate its presence a few tens of feet beneath the scree surface.

There is a natural tendency, upon superficial examination of the structure, to join the Livingstone fault in No. 1 well to the fault beneath Hailstone Butte. Upon closer examination it is obvious that such a correlation is impossible. The throw on the Livingstone thrust at No. 1 well is, as mentioned above, about 7,000 feet: the throw on the Hailstone Butte fault, at its trace three and one-half miles east ,is only 1,500 feet. In addition, at the surface trace of the Hailstone Butte fault, lower Rundle is in contact with Fernie beds at a horizon some 4,000 feet stratigraphically lower than at the No. 1 well. This would necessitate that the fault cut down section as it rises toward the surface. Also arguing against the correlation of the Hailstone Butte fault and the upper fault in Savanna Creek 1, is the fact that the Hailstone Butte fault diminishes in throw southward, and finally disappears at a point on the surface east of Dry Creek.

Another fault must therefore be found to account for the displacement. The next large fault beneath the Hailstone Butte fault is the Livingstone thrust. Its trace is located about three miles east of the mountain front and its throw is 7,000 feet, very similar to the amount of throw on the fault at Savanna 1. The stratigraphic relationships at the fault trace are most suitable to permit a steady rise in section on both sides of the fault plane as encountered in the wells. Indeed, from the facts available no other solution is feasible. The Hailstone Butte fault, and the several smaller thrusts to the east of it are thus shown to be imbrications of the Livingstone sole fault.

Elevations on the Livingstone fault plane in the wells on Dry Creek and eastward at its outcrop along the same line of section show that the highest point on the fault surface is near the No. 1 well. From this apex it obviously dips westward at an angle of at least 30 degrees to an unknown depth. It also dips eastward to the No. 2A well and into the Livingstone river syncline. From beneath Hailstone Butte, it then rises eastward to its outcrop. From the foregoing it becomes apparent that the Livingstone thrust is unmistakeably folded and has been accepted as such by previous writers.

Dipmeter surveys, seismic information, core dips, and stratigraphic data obtained from No. 1 and No. 2A wells, indicate that the strata beneath the Livingstone thrust are also folded. There is no direct evidence to show that the H-N fault undergoes a reversal in dip, but sample, core and dipmeter information show that the beds beneath it are almost certainly folded into a

nearly symmetrical anticline. It is not unreasonable to conclude that the H-N fault, although cutting sharply across the strata, is also folded.

Mechanics of Faulting and Folding

Several theories have been advanced to explain the folding of the Savanna Creek structure. One theory suggests that a group of faults folded together can result from simultaneous faulting and folding. This implies that the older faults are more strongly folded than are the younger ones since they have been subjected to the folding force for a longer period of time. There is no evidence of this. Also implicit in the theory is the necessity of a limited anticline-syncline sequence, (i.e. one anticline and one syncline) through which the faults may pass. Since several folds are known along the Livingstone thrust (including others in the general area), the theory is not applicable to the Savanna Creek structure.

Hume[†] has stated the possibility that, folding may have resulted from movement along a step-fault. This theory required that the faults refract upward on passing from a less competent bed to a more competent bed. As displacement occurs, both the overlying and underlying strata are folded as the result of horizontal movement along the fault. While the authors agree that faults pass through beds of different competence at different angles, there is little evidence at Savanna Creek of warping or defracting of such major proportions. The Livingstone thrust, the principal fault in the structure, must cut at a near bedding plane angle across Plateau anticline and Livingstone River syncline. The H-N fault, on passing from the competent Rundle strata to the relatively incompetent Mesozoics, would be expected to cut less steeply. There is no indication that it does so, and it may actually become steeper. This theory suffers also in being unable to explain the series of folds across the Livingstone thrust.

The authors have constructed many different cross-sections in an attempt to explore the various possibilities; the accompanying cross-sections are believed to fit the facts with the least amount of interpretation. As an example, some doubt exists as to whether or not the faults encountered at depth in No. 1 and No. 2A are one and the same, (the H-N fault). It is not unreasonable to assume that both breaks are along the same fault. This allows for a ismpler interpretation of the structure than by assuming that separate faults were penetrated in each of the wells.

The interpretations favoured by the authors and as shown on the cross-sections, is of faulting followed by folding. According to this interpretation the Livingstone and H-N faults, as well as the unnamed fault at depth in Savanna Creek 3A, originally were gently west-dipping overthrusts. For whatever the reason, be it by continuing compression coupled with the inertia of the overriding mass, basement adjustment, or later and deeper faulting, a fold was imposed upon the structure, thereby warping the strata to their present configuration and folding the included faults. Attendant steeper faulting could be expected, although none of consequence has yet been identified within the structure.

BIBLIOGRAPHY

Irwin, J. S. (1955):	Canada's Mountains: A New Oil Frontier, The Oil and Gas Journal, page 172. The Savanna Creek Structure, Alberta, Canada, Journal of the A.S.P.G., February, page 17.
Link, T. A. (1949):	Interpretation of Foothills Structures, Alberta, Canada, Bulletin A.A.P.G., Vol. 33, No. 9, pageNo. 9, page 1,489-1,490.
Scott, J. C. (1953):	Savanna Creek Structure, A.S.P.G. Field Conference Guide Book, page 134-138.

† Hume, G. S., Fault Structures in Foothills and Rocky Mountains. Paper delivered before A.S.P.G., January, 1957.

TURNER VALLEY OIL AND GAS FIELD

D. G. PENNER [1]

The Turner Valley Oil field is located 25 miles southwest of Calgary, Alberta on the east edge of the Disturbed Belt of the Rocky Mountains. The field is 25 miles long, striking 20° west of north and has a width of one half to three miles. It rates as Canada's first major gas and oil field.

History of Development

The history of development for the Turner Valley Oil and Gas field spans three decades from 1911 to 1945 and falls into three distinct phases: first, the discovery and development of gas and oil from the Cretaceous; second, the discovery and development of gas in the Palaeozoic; and third, the discovery and development of oil in the Palaeozoic.

The first phase was touched off by the initiative of one man, Mr. William Stewart Herron who about 1911 had the gas from a gas seep analyzed for possible content of higher hydro-carbons than is normally found in seeps. The results of the analysis led to a chain of events which are described in detail by F. K. Beach (1956). Briefly, the events culminated, early in 1913, in the drilling of a well not far from the location of the gas seep in Lsd. 14 of Sec. 6, Twp. 20, Rge. 2, W.5th M. The following year this well obtained a flow of gas and small quantity of oil from the Cretaceous at a depth of 1,557 feet. The gas contained a vapor that would condense to almost pure gasoline and could be utilized as such without refining.

Following this discovery two more wells were started and a small absorption plant was built. On October 20, 1920, a fire destroyed the plant. The necessary refinancing of the original company saw the beginning of Royalite Oil Company, Limited. This company rebuilt the absorption plant and started a new well, called Royalite 4 in Lsd. 12 of Sec. 7, Twp. 20, Rge. 2, W.5th M. In 1924, this well reached the Palaeozoic at 3,450 feet and at a depth of 3,740 the tools encountered a large flow of naphtha- bearing gas. Thus began phase two.

During this period (1924-1936), several wells were drilled more or less along strike with Royalite 4 and completed as gas wells. One of these wells, Model No. 1, in Lsd. 8 of Sec. 22, Twp. 20, Rge. 3, W.5th M., completed in 1931, yielded a dark colored oil which had to be distilled. Such a product was penalized in price which discouraged drilling farther down the west flank. This well is now regarded as the first to indicate possible crude oil on the west flank. It was not until 1936 that Turner Valley Royalites was drilled in Lsd. 13 of Sec. 28, Twp. 18, Rge. 2, W.5th M. The location was toward the west flank and it yielded a small flow of gas but a substantial amount of liquid phase oil. As such, it confirmed the indications of Model No. 1, and touched off the third phase which saw rapid development of the oil area between 1936 and 1945.

Structure

The history of geological interpretation of the Turner Valley structure is described by Theo. A. Link (1949 and 1953) and these accounts are definitely recommended to the reader. The present day concept of the structure is described by Link (1953) in such a concise manner that it is repeated here.

"The Turner Valley structure is an asymmetrical, highly faulted, anticlinal structure involving Palaeozoic sediments, and is underlain by a low-angle (possibly folded or warped) major sole fault on which it was carried eastwardly during the Laramide orogeny. It is slightly arcuate

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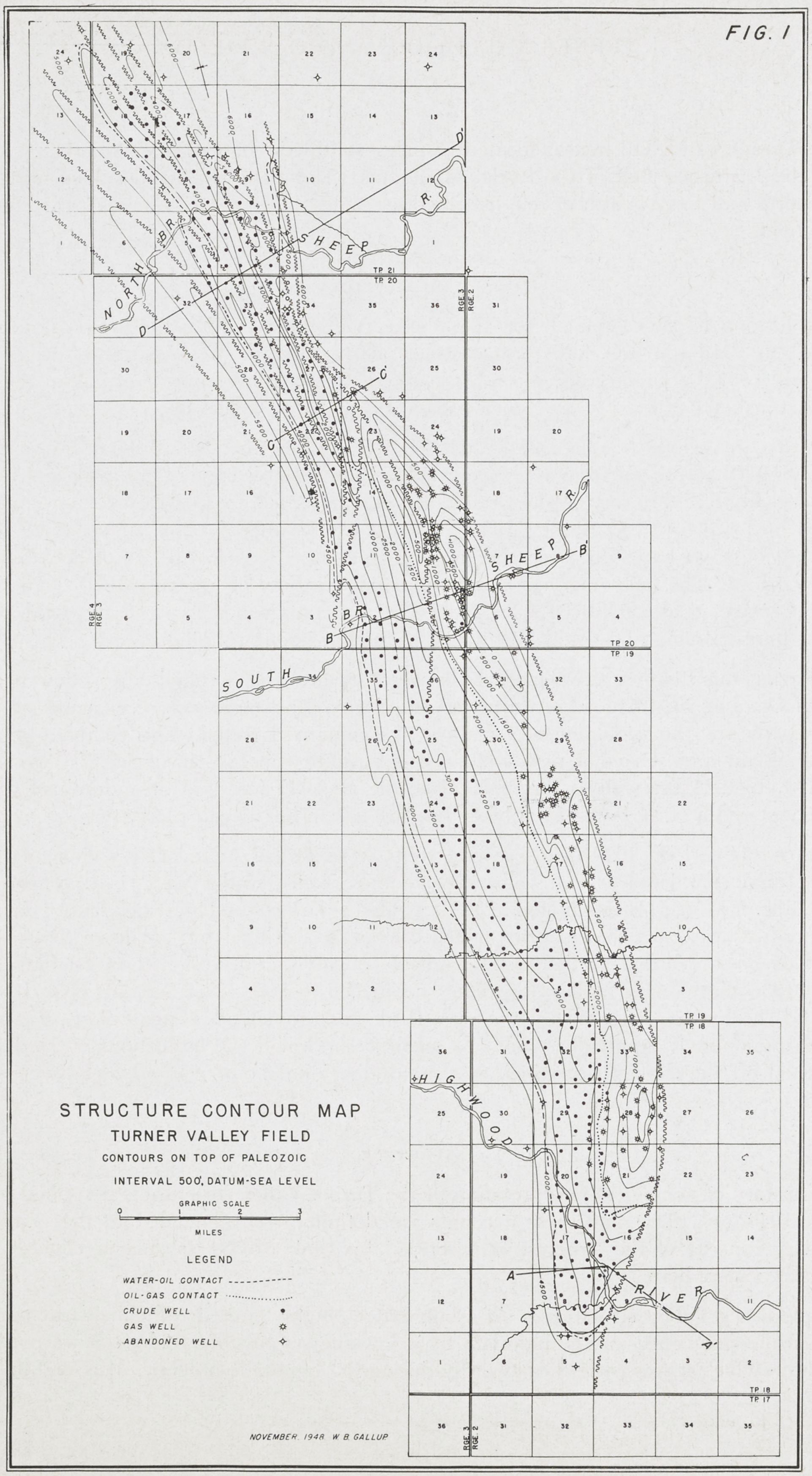
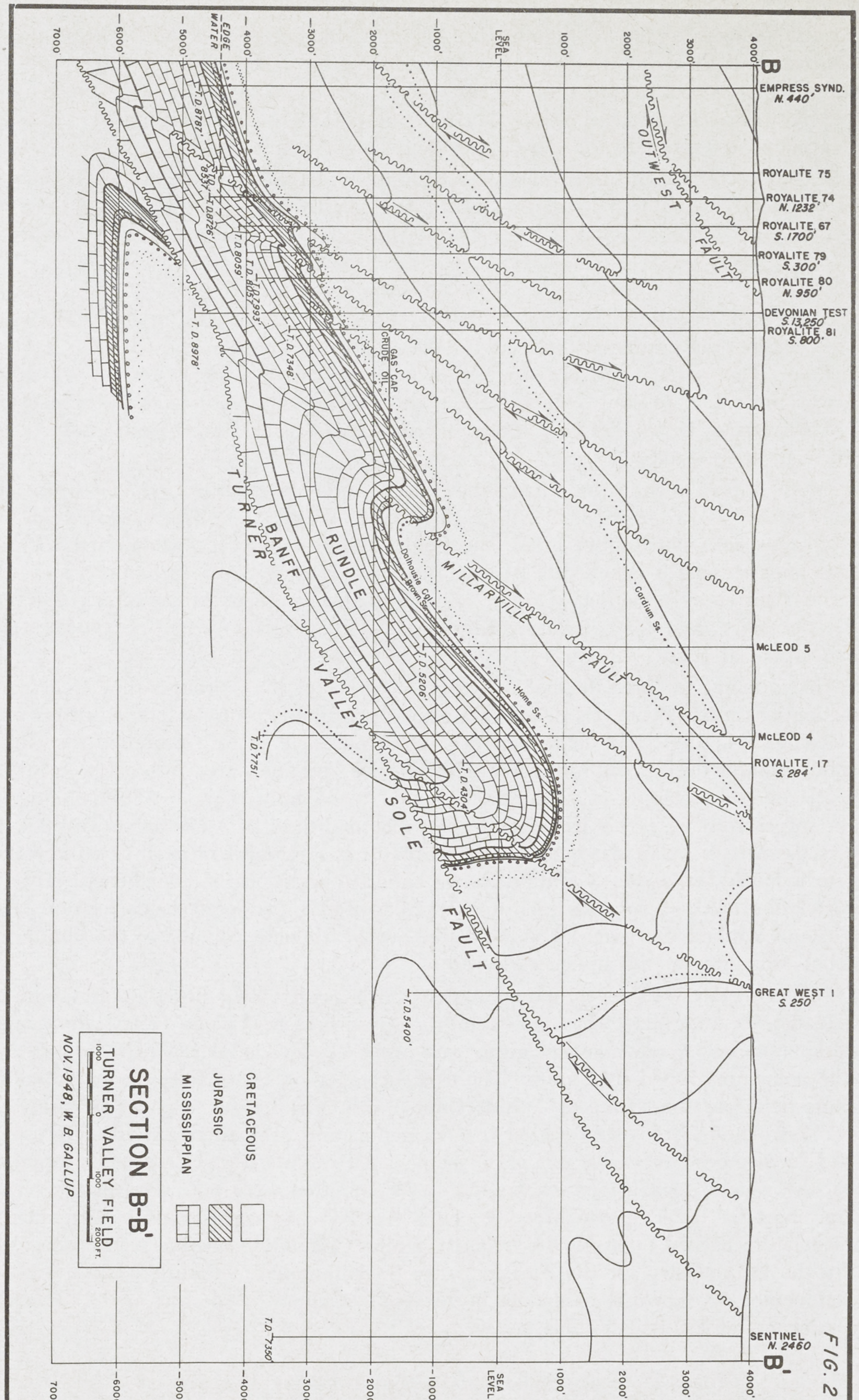


FIG. I
STRUCTURE CONTOUR MAP
TURNER VALLEY FIELD
CONTOURS ON TOP OF PALEOZOIC
INTERVAL 500', DATUM-SEA LEVEL
GRAPHIC SCALE
MILES
LEGEND
WATER-OIL CONTACT
OIL-GAS CONTACT
CRUDE WELL
GAS WELL
ABANDONED WELL
NORTH BR. SHEEP R.
SOUTH BR. SHEEP R.
HIGHWOOD RIVER
TP 21
TP 20
TP 19
TP 18
TP 17
RGE 4
RGE 3
RGE 2
NOVEMBER 1948 W.B. GALLUP


SECTION B-B'
TURNER VALLEY FIELD
NOV. 1948, W. B. GALLUP
CRETACEOUS
JURASSIC
MISSISSIPPIAN
B
B'
EMPRESS SYND. N. 440'
ROYALITE 75
ROYALITE 74 N. 1232'
ROYALITE 67 S. 1700'
ROYALITE 79 S. 300'
ROYALITE 80 N. 950'
DEVONIAN TEST S. 13,250'
ROYALITE 81 S. 800'
McLEOD 5
McLEOD 4
ROYALITE 17 S. 284'
GREAT WEST 1 S. 250'
SENTINEL N. 2460
OUTWEST FAULT
MILLARVILLE FAULT
TURNER VALLEY SOLE FAULT
RUNDLE
BANFF
GAS CAP
CRUDE OIL
EDGE WATER
Cardium Ss.
Home Ss.
SEA LEVEL
4000'
3000'
2000'
1000'
-1000'
-2000'
-3000'
-4000'
-5000'
-6000'
7000'
FIG. 2

in shape and plunges to the south into the Alberta Syncline and to the north underneath another thrust sheet involving the Palaeozoic limestone, termed the Millarville thrust fault, which is topographically a north extension of Turner Valley. The oil and gas production is obtained from the biostromal limestone-dolomite horizons in the Madison limestone of Mississippian age and accumulated prior to the development of the major sole faulting."

W. B. Gallup, (1951), made a valuable contribution to the literature of the Turner Valley field. His structure contour map of the top of the Mississippian limestone and cross-section through the field, Figures 1 and 2 respectively, illustrate the concept described above.

Stratigraphy

The stratigraphic column of Turner Valley field was known as early as 1929. The existence of two distinct porous producing horizons in the Palaeozoic limestone had been established by that time. The porous horizons were known to overlie a dark limestone which, when reached was the signal to stop drilling. These three important horizons were named by the drillers. Their terms "Upper Porous", "Lower Porous" and "Black Lime" were gradually established through long usage.

The Mississippian section underlying the "Black Lime" is recorded by one well, namely, Devonian Test No. 1 (Lsd. 2 of Sec. 25, Twp. 19, Rge. 3, W.5th M.). It was started in 1942 to explore the Devonian possibilities under the field. Unfortunately it encountered the Turner Valley sole fault at what is believed to be near the base of the Banff formation, and the bit entered the Blairmore formation. (Figure 3). The near-complete Mississippian section provided the necessary data for correlating the Turner Valley section with the type outcrop of the Mississippian at Banff, Alberta.

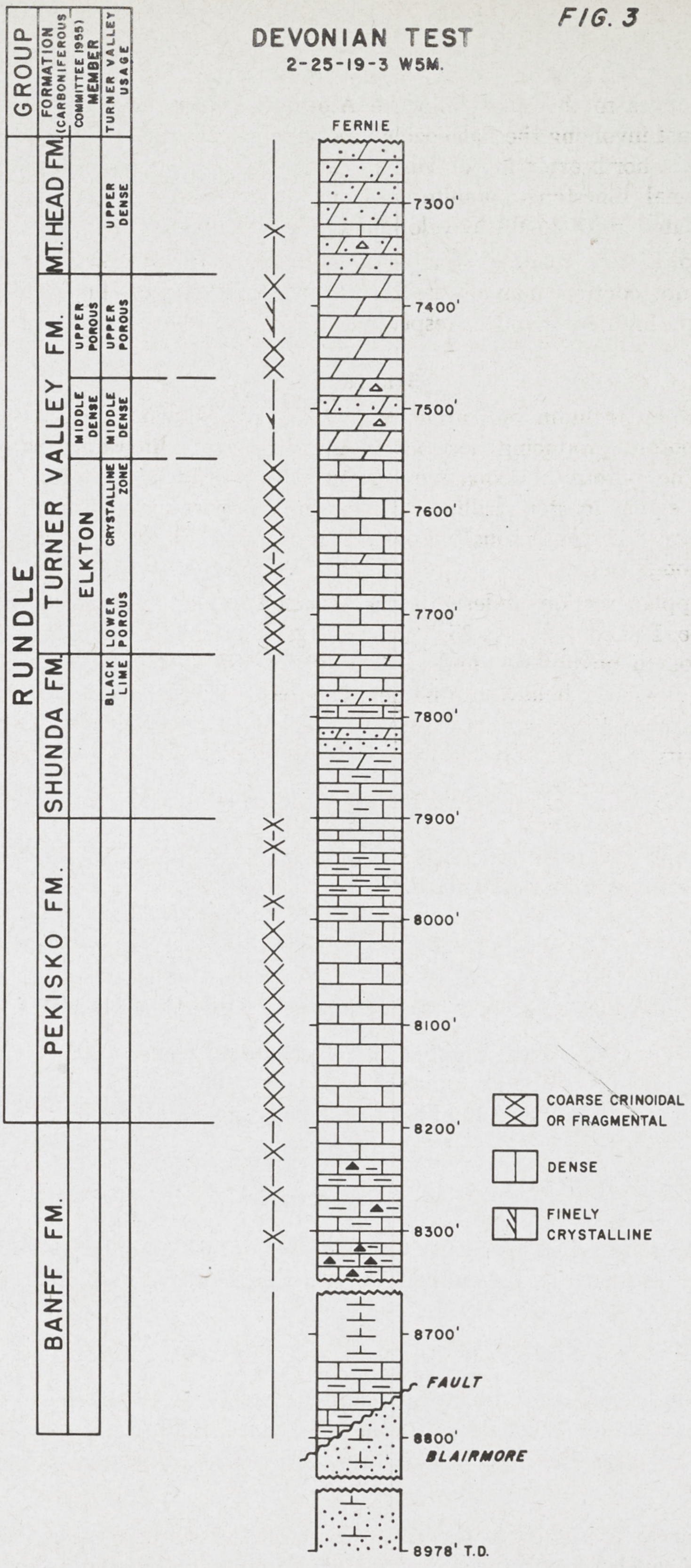
The first attempt to correlate the Mississippian strata of the Turner Valley field with the Banff section was made by H. H. Beach in a paper presented to the Alberta Society of Petroleum Geologists in 1947. The main part of Beach's talk dealt with a proposed threefold lithologic subdivision of the Rundle formation of the Rocky Mountain area into a lower carbonate, a middle clastic and an upper carbonate, and named these units Dyson, Shunda and Tunnel Mountain respectively. Beach's correlation chart included the log of Devonian Test No. 1. Inasmuch as the Mississippian strata overlying the Banff at this well lent itself to a threefold subdivision to a lower carbonate, a middle clastic and an upper carbonate Beach proposed a direct correlation of the respective rock units. Gallup, (1951), adopted the correlation proposed by Beach, and applied the names Dyson to the lower carbonate, Shunda to the middle clastic and Tunnel Mountain to the upper carbonate.

R. J. W. Douglas, (1953), proposed a new subdivision of the Rundle formation in the Mount Head area and faced these units in the subsurface in Turner Valley, Jumpingpound and Pekisko regions. A new nomenclature was proposed by Douglas which did not include any of the names published by Gallup. The existence of two sets of names for the same interval in the same field was the source of considerable confusion in the industry. In 1954 the Alberta Society of Petroleum Geologists decided to take action and appointed a Carboniferous Committee of five members to resolve one set of names. Although a few differences of opinion still remained, the general conclusions reached by the Committee were published in the form of a correlation chart for the Regional Meeting of the A.A.P.G. at Jasper in 1955. The subdivision and nomenclature agreed upon by the majority of the Committee members ,and generally accepted by the Oil industry for the Turner Valley field is shown in Figure 3. The thickness of the Elkton member as shown is anomalous in this well. Gallup (1951 and 1954), indicates an average thickness of 130 feet for this unit.

Porosity, Permeability, and Thickness of Pay Zones

Very few core analysis data are available but microscopic examination of samples indicate

FIG. 3


DEVONIAN TEST
2-25-19-3 W5M.
GROUP
FORMATION (CARBONIFEROUS)
(COMMITTEE 1955) MEMBER
TURNER VALLEY USAGE
RUNDLE
MT. HEAD FM.
TURNER VALLEY FM.
SHUNDA FM.
PEKISKO FM.
BANFF FM.
ELKTON
UPPER DENSE
UPPER POROUS
MIDDLE DENSE
CRYSTALLINE ZONE
LOWER POROUS
BLACK LIME
FERNIE
7300'
7400'
7500'
7600'
7700'
7800'
7900'
8000'
8100'
8200'
8300'
8700'
FAULT
8800'
BLAIRMORE
8978' T.D.
COARSE CRINOIDAL OR FRAGMENTAL
DENSE
FINELY CRYSTALLINE

that the average porosity is 7 percent for the "Upper Porous zone" and 7.8 percent for the "Lower Porous zone".

The average permeability in the two reservoirs is approximately 7 millidarcies.

The total average thickness of both porous zones is 146 feet.

Production and Number of Wells

The field has produced to the end of 1956 as follows:

Palaeozoic Production

	Barrels
1. Crude oil	100,387,590
2. Naphtha	11,333,112
3. Absorption gasoline	10,694,570
4. Propane	989,405
Total	123,404,677

Post-Palaeozoic (Jurassic and Cretaceous Sands)

	Barrels
1. Crude oil	529,023
Total petroleum for field	123,933,700

	Mcf.
Natural gas from Palaeozoic	1,747,356,822
Natural gas from post-Palaeozoic	12,904,364
Total gas	1,760,261,186

The number of wells capable of production as of December 31, 1956 is as follows:

Total number of Palaeozoic oil wells – 302
Total number of gas wells – 96
Total number of post-Palaeozoic oil wells–2

Reserves and Recovery

The original crude oil in place is estimated to be 1,050 million stock tank barrels. The primary recovery estimate is 124 million or 12 percent recovery of oil in place.

Secondary Recovery for Turner Valley?

A detailed study was made by Royalite Oil Company as to the possibilities of secondary recovery in Turner Valley field. It was concluded that a field trial was warranted and a water flood appeared to offer the best possibilities. The water injection project was started in August, 1948.

In 1955, Harvie presented a progress report on the Turner Valley Water Flood project at the Annual Convention of the C.I.M.M. at Edmonton, Alberta, in which he concluded that "an economic consideration of the results to date clearly shows the flood to be a financial success".

REFERENCES

Beach, F. K. (1956): Turner Valley Discovery and Development; Canadian Oil & Gas Industries, February, pp. 42-45.

Douglas, R. J. W. (1953): Carboniferous Stratigraphy in the Southern Foothills of Alberta; Alta. Soc. Petrol. Geol. Third Annual Field Conference and Symposium, pp. 68-88.

Gallup, W. B. (1951): Geology of Turner Valley Oil and Gas Field, Alberta, Canada; Bull. Amer. Assoc. Petrol. Geol., Vol. 35, No. 4, pp. 797-821, Reprinted with revisions in Rutherford Mem. Vol., pp. 397-414, 1954.

Harvie, J. A. (1950): Secondary Recovery for Turner Valley?; The Oil and Gas Journal, December 21.

Link, Theo. A. (1949): Interpretations of Foothills Structures, Alberta, Canada; Bull. Amer. Assoc. Petrol. Geol., Vol. 33, No. 9, pp. 1475-1591, 1949. Reprinted in Rutherford Mem. Vol., 1954.

(1953): History of Geological Interpretation of the Turner Valley Structure and Alberta Foothills, Canada; Alta. Soc. Petrol. Geol., Third Annual Field Conference and Symposium, pp. 117-133.

PINCHER CREEK GAS-CONDENSATE FIELD

BY H. S. RHODES [1]

Location

The Pincher Creek field is located between 11½ and 19 miles southeast of the town of Pincher Creek on highway No. 31 ,which leads to Waterton Park. Calgary is located approximately 100 miles due north of the field.

History

The general Pincher Creek-Waterton area had a very long and disappointing history in regard to oil exploration and drilling until the discovery of gas at the Pincher Creek gas field by Canadian Gulf Oil Company in 1947. In the early days, before the advent of settlers in Southern Alberta, the Indians attracted by oil seepages on Cameron Creek west of Waterton Lakes. This oil was used by the Indians for medicinal purposes. Through persuasion the settlers found the source of the Indians' oil and used it to great advantage for greasing their wagons and other farm machinery. In 1902 a well, Lineham No. 1, was drilled to a depth of 1,900 feet. At 1020 feet oil in uncommercial quantities was found. A second well drilled about the same time west of Waterton Lakes spudded into Precambrian rocks and at 1500 feet faulted into Upper Cretaceous rocks of the Benton formation. This well was the first to penetrate the Lewis overthrust and indicates that the oil found along Cameron Creek was seeping through the overthrust from the Cretaceous beds below. By the end of 1946, 24 wells had been drilled and abandoned without reaching the Palaeozoic limestone or finding oil or gas in commercial quantities in the Pincher Creek-Waterton area. In April of 1947, after an extensive geophysical program, Canadian Gulf spudded what was to become the discovery well of the Pincher Creek gas-condensate field. Pincher Creek No. 1, located in Lsd. 15, Sec. 24, Twp. 3, Rge. 29, W.4th M., contacted the top of the Rundle limestone at 11,705 feet and has a final total depth of 12,516 feet. The well was completed June 19, 1948 with an indicated open flow of 45 MMcf/d of gas and 1670 barrels of distillate per day. Pincher Creek is Alberta's largest gas-condensate field.

Stratigraphy

The Pincher Creek reservoir is overlain by 12,000 feet of Recent, Pleistocene, Cretaceous and Jurassic clastic rocks. The complete Mississippian section has not been fully penetrated.

Listed below is a break-down of the Mississippian system:—

Mount Head Formation

The Mount Head formation is approximately 150 feet thick and is composed of slightly silty and argillaceous, dense dolomites and recemented breccia. Stringers of crystalline dolomite are found throughout the zone but are more abundant near the base. Some intergranular porosity is present, and fractures are in part lined with calcite, quartz and solid black hydrocarbons.

Turner Valley Formation

Upper Porous Member

There is approximately 120 feet of the Upper Porous member. Lithologically it is composed of fine to medium crystalline porous dolomite with thin layers of fine to dense

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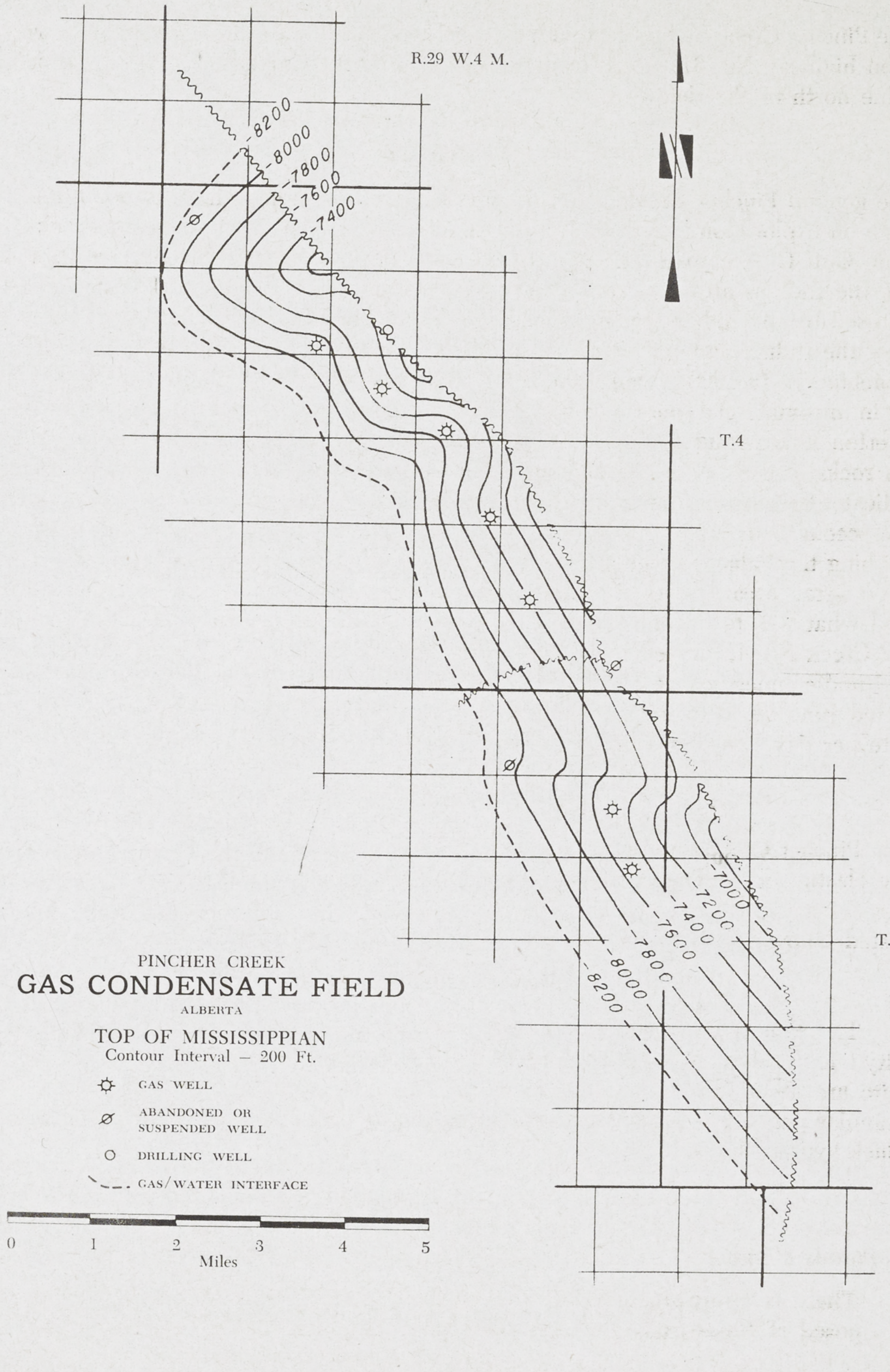

R.29 W.4 M.
T.4
T.3
8200
8000
7800
7600
7400
7000
7200
PINCHER CREEK
GAS CONDENSATE FIELD
ALBERTA
TOP OF MISSISSIPPIAN
Contour Interval — 200 Ft.
GAS WELL
ABANDONED OR SUSPENDED WELL
DRILLING WELL
GAS/WATER INTERFACE
0 1 2 3 4 5
Miles

dolomite. Permeability is enhanced by the presence of vertical and diagonal fractures.

Middle Dense Member

This member has an average thickness of less than 50 feet and is composed of finely crystalline, calcareous, dolomite, interbedded with silty, argillaceous and cherty dolomite. Some intervals of clean dolomite have intergranular porosity. Vertical and horizontal fractures are present throughout.

Elkton Member

The Elkton member has a thickness of between 233 feet and 193 feet. Lithologically it is composed of interbedded crystalline dolomite and coarsely crystalline, fragmental limestone. Well developed porosity is present in part of the dolomite and to a lesser extent in the limestone. Fractures are present.

Shunda Formation

The full thickness of this formation has not been penetrated in any of the wells drilled at Pincher Creek. However, where it has been drilled into it is composed of normal marine to coarse fragmental limestones with interbeds of dense to finely crystalline dolomite.

Structure

The surface at Pincher Creek gas field is faulted with numerous closely spaced thrust faults that trend between north 40° west and north 60° west.

Erdman (1953) states that the subsurface structure of the Pincher Creek field is a doubly plunging thrust block of Mississippian limestone with a gentle dip of between 4° and 8° to the southwest and a strike of north 30° west.

The field limits are as yet not fully defined. The gas/water interface is taken at a subsea elevation of –8200 feet, this would place the western limits of the field just east of the third well drilled in the field, Fred Schrempp No. 1 located in Lsd. 4, Sec. 35, Twp. 3, Rge. 29, W.4th M. This well contacted the top of the Rundle group at a subsea elevation of –8066 feet and the Upper Porous member at a subsea elevation of –8232 feet ,or 32 feet below the gas/water interface. The northern limit has been reached and lies slightly south of Rudolf No. 1, located in Lsd. 11, Sec. 31, Twp. 4, Rge. 29 W. 4th M. This well contacted the top of the Rundle group at a subsea elevation of –8118 feet and the Upper Porous member at a subsea elevation of –8267 feet or 67 feet below the gas/water interface. The eastern limit of the field is very abrupt due to the thrust fault. However, this side of the field has not been definitely established although a well, F. M. Huddlestun No. 1, located in Lsd. 6, Sec. 1, Twp. 4, Rge. 29 W 4th M., contacted the Upper Porous member at 190 feet below the gas/water interface (–8390 feet). This well may have been drilled on the downthrow side of a fault block, and the field limits could extend quite a distance east on the north and south side of the Huddlestun well. The southern limit of the field is not as yet defined.

Production

Ten wells have been drilled in the Pincher Creek field. Of the ten wells, seven are completed gas wells and three have the status of suspended or abandoned wells. These suspended wells contacted the Upper Porous member below the gas/water interface. The eleventh well, Ray Marr No. 1, located in Lsd. 7, Sec. 28, Twp 4, Rge. 29, W. 4th M., is currently drilling.

Reservoir Factors and Reserve Estimates*

Reservoir Rock: - - - - - Turner Valley Formation

* Figures from the Reservoir Engineering Digest.

Age:	Mississippian (Osagean)
Rock Type:	Dolomite
Type Gas:	Non-associated
Specific Gravity (Air=1):	0.58
Heat Valve BTU/CF:	1,042
Average Well Depth:	11,700 feet.
Gas/Water Interface:	8200 feet subsea
Average Thickness of Pay Zone:	389.1 feet
Porosity:	4.62 per cent
Connate Water:	16 per cent
Original Pressure:	4,945 P.S.I.A.
Reservoir Temperature:	191° F.
Original Gas In Place:	3,631.3 billion cubic feet
Gross Absolute Open Flow/Well/pay:	75 MMcf
	CO^2 and H^2S makes up 17 per cent of the gas
Permeability Type:	10 per cent Intergranular — 90 per cent Intermediate

Pincher Creek at the present time has the status of a shut-in gas field and will remain as such until the completion of at least part of the Trans Canada Pipe Line. Trans Canada Pipe Line has a contract with the British American Oil Company (Formerly Canadian Gulf Oil Company) whereby they will buy 100 MMcf/d of gas during their first year of operation and 170 MMcf/d in subsequent years. British American Oil Company has just finished building a sulphur plant in the Pincher Creek field inorder to prepare the gas for delivery to Trans Canada Pipe Line. This plant will be capable of processing 170 MMcf of crude natural gas per day from which it will recover 780 long tons of sulphur, 1230 barrels of propane, 1300 barrels of butane, 1020 barrels of natural gasoline and 7810 barrels of condensate.

BIBLIOGRAPHY

Daly, R. A., (1912): Geology of North American Cordillera at the Forty-ninth Parallel, Geol. Surv. Can.; Mem. No. 38, pp. 1-546.

Douglas, R. J. W., (1951): Preliminary Map, Pincher Creek, Alberta, Geol. Sur. Can., Paper No. 51-22.

Erdman, O. et al, (1953): Pincher Creek Area, Alberta, Alta. Soc. Pet. Geol., Third Annual Field Conference Guide Book, pp. 139-157.

Gallup, W. B., (1955): Pincher Creek and its Regional Implications, Billings Geol. Soc., Sixth Annual Field Conference Guide Book, pp. 150-159.

Hume, G. S. and Ignatieff, A., (1950): Natural Gas Reserves of Prairie Provinces, Geol. Surv. Can., Special Report, pp. 243-248.

MEDICINE HAT GAS FIELD

C. D. McCORD [1]

Introduction

"Attention was first directed to the gas possibilities of Medicine Hat area by the seepages of gas in the South Saskatchewan River (Hume, 1933). Gas was first produced from the Milk River sandstone at a depth of 700 feet in 1901 and in 1908 the Canadian Pacific Railway drilled the 1,000 foot discovery well to the Medicine Hat sandstone. This reservoir has produced all of the gas used by industrial and domestic consumers since that time. Development has been concentrated in the vicinity of the cities of Medicine Hat and Redcliff and during the last few years a number of exploratory wells have been drilled in the more easterly portions of the field. The average depth to the Medicine Hat sand in the field area is 1,150 feet, and the occurrence of gas at this shallow depth has contributed to the growth of Medicine Hat as an industrial city. Ceramics, brick and glass manufacturer are three of the main industries. Brick clay is recovered from the Oldman formation that outcrops in the valley of the South Saskatchewan River.

The Reservoir

The Medicine Hat gas reservoir is comprised of the sandstones of the Medicine Hat member, of the Upper Cretaceous Colorado formation which lies between the First and Second Speckled Shale zones approximately similar to the Cardium Formation of western Alberta. The Medicine Hat sandstones are generally very fine grained, and quartzose, and are interbedded or interlaminated with shale. However, the characteristics vary over a wide range, the sandstones can be: medium to fine grained; brown grey with rounded chert pebbles to salt and pepper; clean to micromicaceous to argillaceous and in part calcareous; and well sorted to poorly sorted.

An isopachous map of the porous thickness of the Medicine Hat Member, (Fig. 1), reveals a long lenticular shaped body that thins to the west, north and east. The recovery of water on drill stem tests in two wells, (Lsd. 7, Sec. 14, Twp. 10, Rge. 4, W4M, and Lsd. 6, Sec. 30, Twp. 11, Rge. 7, W4M) in the southwest map area indicates that a porosity barrier also exists on the updip southwest margin of the field.

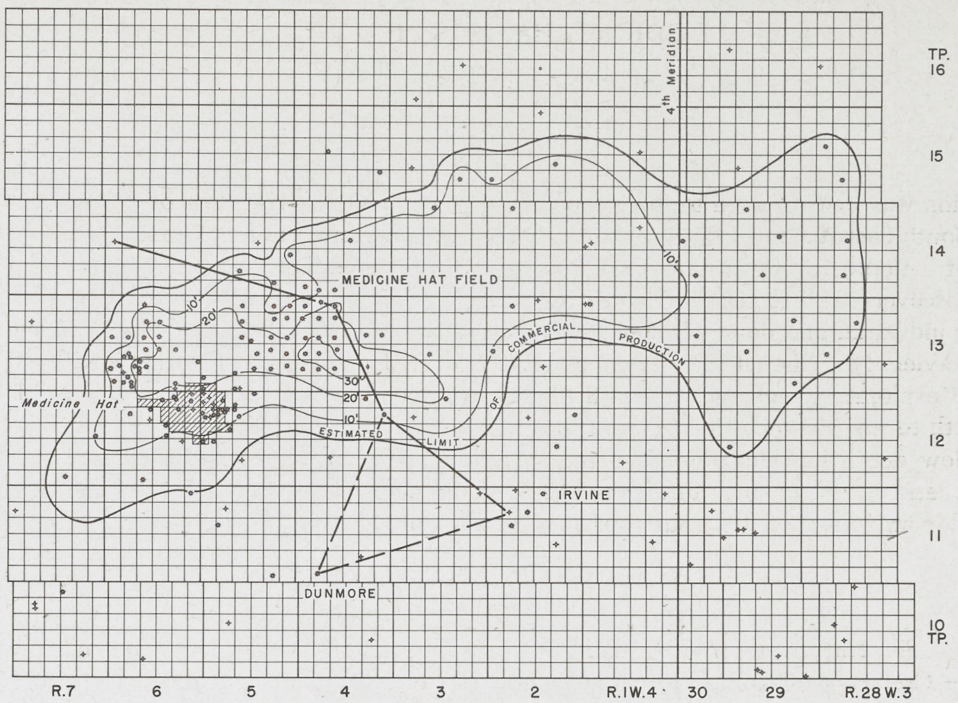
The Medicine Hat gas sand is located on the northeast flank of the Sweetgrass Arch in an area where the northeast plunging arch joins in with the southwest plunging North Battleford high to form a regional saddle. This flank location suggests a derivation of sediments from an emergent area on the axis of the Arch. However, a section of Colorado shale in southern Alberta shows an uniform thickness over the Arch and the east flank area around Medicine Hat; appreciable thickening occurs only on the west flank (Spratt, 1931).

The shape of the porous reservoir conforms closely to the shape of a broad northeast plunging nose structure, (Fig. 3). This condition suggests that the Medicine Hat nose was at an optimum depth for the reworking of Colorado sediments by waves and currents which resulted in a concentration of arenaceous material on a shoal in a shallow sea. The unclean, poorly sorted, variable character of the sandstone supports this reasoning.

Source Beds

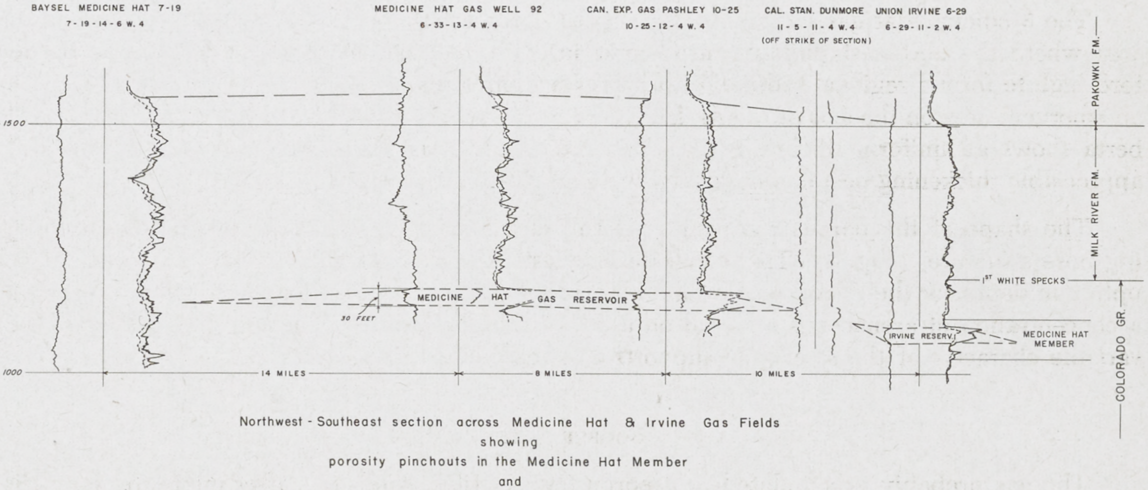
The gas probably accumulated in a porous, water filled sandstone after migrating short distances from the Upper Colorado marine shales that lie above and below the Medicine Hat Member.

[1] Geologist, Cree Oil of Canada.



MEDICINE HAT FIELD
showing
net pay isopach Medicine Hat Gas Sand
Interval 10 feet

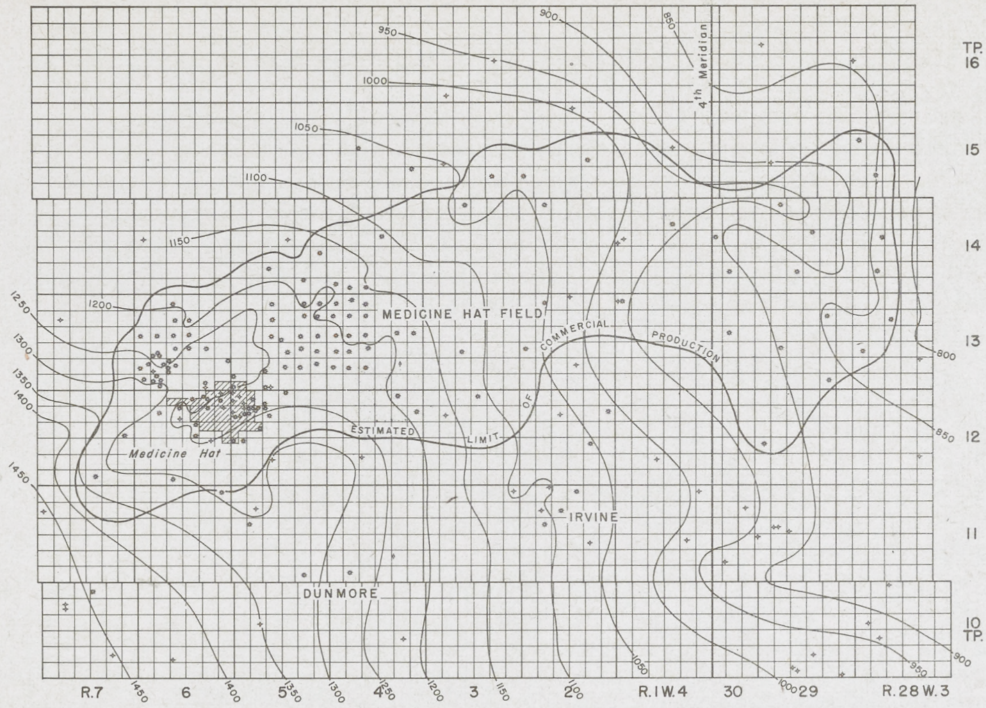
Fig. 1



Northwest - Southeast section across Medicine Hat & Irvine Gas Fields
showing
porosity pinchouts in the Medicine Hat Member
and
Northeast plunging nose structure
Section based on sea level

C.D. McCord

Fig. 2



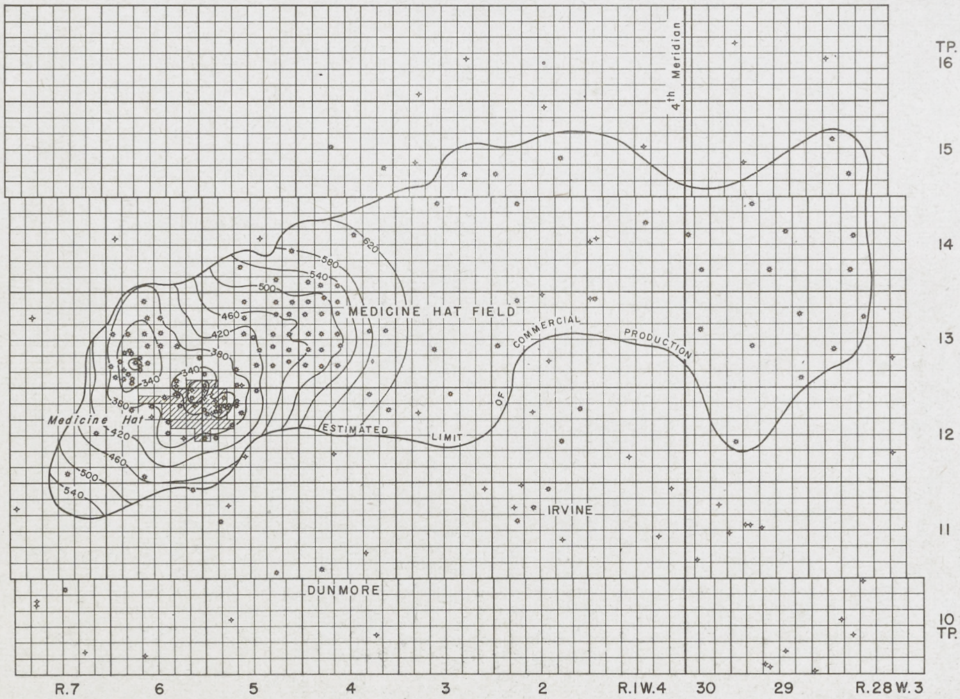
MEDICINE HAT FIELD
showing
contours on top of Medicine Hat Sandstone
Interval 50 feet

- Location - drilling
- Suspended - standing
- Gas well
- Abandoned well

C.D. McCord
J.A. Downing

SCALE IN MILES
0 5 10 15 20 25

Fig. 3



MEDICINE HAT FIELD
Isobaric map of Medicine Hat Sandstone
1956 pressure survey
Interval 40 P.S.I.

- Location - drilling
- Suspended - standing
- Gas well
- Abandoned well

R.R. McDaniel
J.A. Downing

SCALE IN MILES
0 5 10 15 20 25

Fig. 4

Structure

The lenticular gas reservoir is located on a broad tectonic northeast plunging nose which is related to the regional Sweetgrass Arch to the southwest. The structure of the field apparently was not a direct control factor for the accumulation of the gas. It is suggested above that the structure was the cause for sorting of material and in turn is resonsible for the lithologic facies change that acts as barrier on the margins of a closed lens of porous sandstone. Certainly the shales appear to be on the flanks of the nose structure of the reservoir and structure could be valuable in predicting the limits of the porous reservoir. The limit of the field is dependent only on the characteristics of the sandstone.

Reservoir Characteristics

The Medicine Hat Field has a drainage area of at least 296,000 acres and the average net gas pay is estimated to be 20 feet. The porosity and connate water are estimated to be 18% and 25% respectively. As the majority of the wells were drilled before 1945 there is very little accurate information regarding porosity, permeability, or connate water content of the reservoir rock. Figure 4 is an isobaric map showing the pressures for the wells in the field as determined by the Petroleum and Natural Gas Conservation Board of Alberta in 1956. The lowest pressures occur where the oldest producing wells are located and where most gas has been produced. Gas is migrating from all direction to the pressure low and in some wells situated in the low where only small amounts of gas had been produced during 1955-1956 the pressures have increased during the producing period. This indicates that more gas is migrating to the well bore than is being produced. The gas is clean and relatively dry. The following is a typical analysis:

Methane	–	95.71%
Ethane	–	0.15%
Propane	–	0.06%
Iso butane	–	0.04%
Nitrogen	–	3.78%
Carbon Dioxide	–	0.26%

		100.00%

There have been various estimates of the gas reserves of the Medicine Hat Field varying from 1,000 billion cubic feet upwards.

The total gas production from the field to the end of 1956 is estimated to be 194 billion cubic feet. Here again past records of production are not accurate. Some of the wells were flared for days and consequently the production history is at best an estimate.

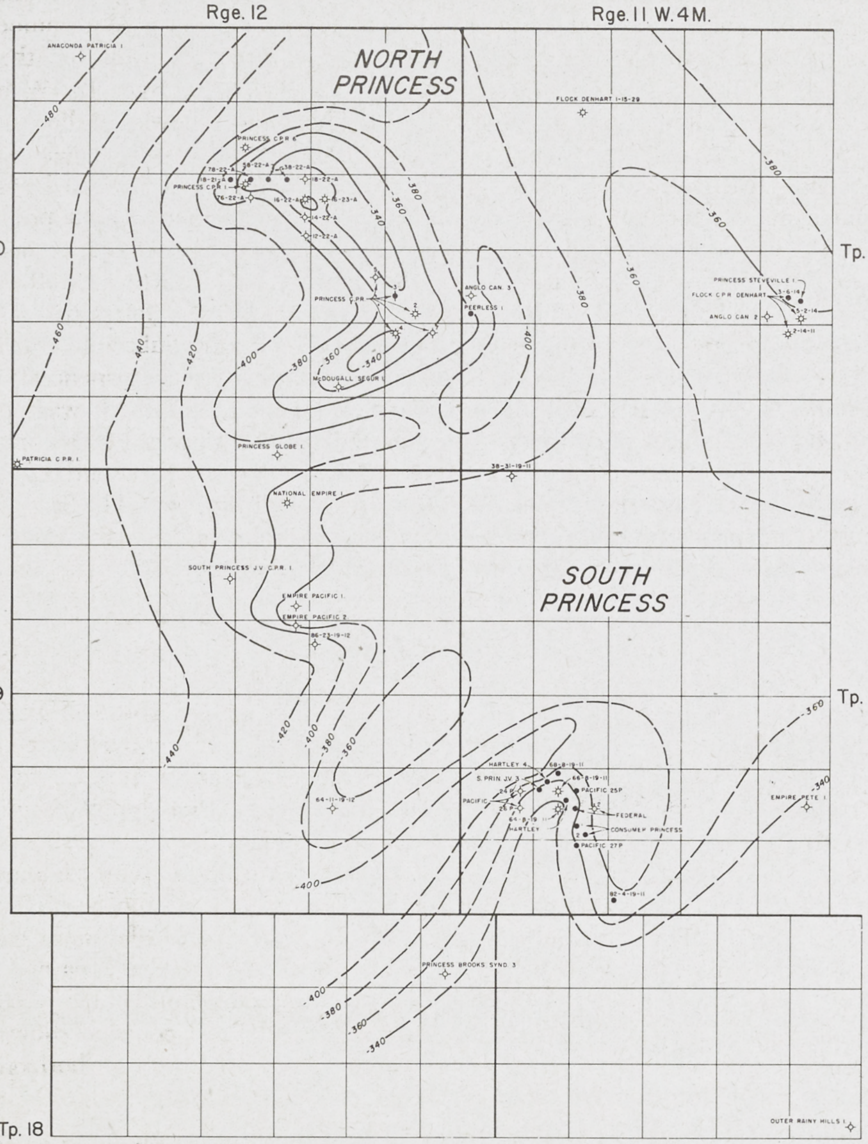
Bibliography

Dowling, D.B., Slipper, S. E., and McLean, F. H. (1919): Investigations in the Gas and Oil Fields of Alberta, Saskatchewan and Manitoba; Geol. Surv. Can., Mem. 116.

Hume, G. S. (1933): Oil and Gas in Western Canada; Econ. Geol. Ser., #5, Can. Dept. Mines, pp. 148.

Russel, L. S., and Landes, R. W. (1940): Geology of Southern Alberta Plains; Geol. Surv. Can., Mem. 221.

Spratt, J. G. (1931): Stratigraphy of Colorado Shale in Southern Plains of Alberta; Bull. Amer. Assoc. Petrol. Geol., Vol. 15, No. 10, pp. 1171.



PRINCESS AREA

STRUCTURE CONTOURS ON TOP OF THE BLAIRMORE FORMATION

SCALE IN MILES

0 1 2 3 4 5

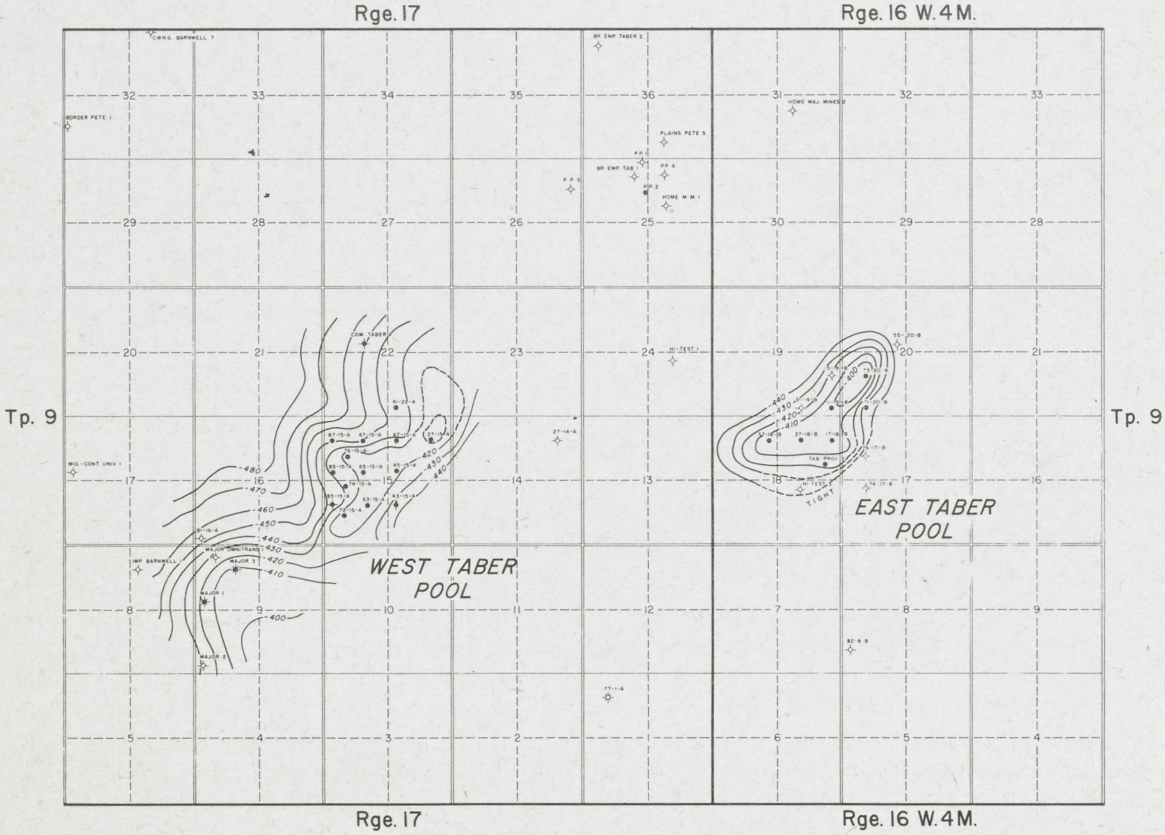
B-7559-1
SS-3

PRINCESS OIL AND GAS FIELD

The Princess oil and gas field is situated in Twps. 18, 19 and 20, Rges. 11 and 12, W.4th M., approximately 140 miles east of the city of Calgary. The area consists of a number of hydrocarbon pools of varying trap types and reservoir age. The discovery well for the field area was Princess C.P.R. No. 1, located in Lsd. 16, Sec. 22, Twp. 20, Rge. 12, W.4th M. The well location was based upon seismic geophysical work which had followed earlier surface reconnaissance work. This well was completed in August, 1940 after discovering gas and oil shows in many horizons. The well caused widespread interest when it blew wild in December, 1939 and was instrumental in indicating that the plains of Western Canada might produce prolific oil and gas fields. Following considerable testing the well was completed as a gas well in the "Sunburst" sand of Lower Cretaceous age. In September, 1944 Princess C.P.R. 18-21-A was completed as an oil well from the 2nd Porous zone at the top of the Jefferson. This was the first commercial Devonian oil show on the Western Canadian Plains. Subsequent drilling proved a small oil accumulation which produced 334,000 barrels before being suspended. South Princess Joint Venture No. 3 well in Lsd. 12, Sec. 8, Twp. 9, Rge. 11, W.4th M. was completed on October 27, 1946. This was the discovery well for the South Princess Mississippian oil pool. The Mississippian in the Princess area has produced 465,000 barrels. Just south of the map area the California Standard Imperial Bantry C.P.R. No. 1 well in Lsd. 11, Sec. 2, Twp. 19, Rge. 13, W.4th M. was completed on January 3, 1948 as a producer from the Basal Cretaceous sand. This small pool had produced 266,000 barrels to the end of 1956.

Aside from the above oil production there are numerous gas accumulations present in the area. Going upwards through the stratigraphic section, high pressure gas, very high in Nitrogen content, was found in the lower part of the Jefferson formation. This accumulation appears to extend over part of the closed area at North Princess. The 2nd Porous zone at the top of the Jefferson, as previously mentioned, contains oil and gas over part of the closed area of North Princess. The 1st or Upper Porous zone of the Jefferson appears to contain gas over the entire closed area at North Princess. The top of the Mississippian, aside from production at South Princess has had semi-commercial oil shows in the North Princess area. The weathered chert zone which lies at the base of the Cretaceous contains semi-commercial oil and gas shows in the Empire Pacific area and around the flank of part of the North Princess area. The so-called Sunburst or Princess sand which lies at the base of the Blairmore contains large volumes of gas and semi-commercial volumes of oil in the North Princess area and at the California Standard Patricia C.P.R. No. 1 well. The Basal Colorado sand probably contains commercial or semi-commercial gas in the area. The Bow Island Sand contains shows of gas and oil in the Denhart area and one well produced light gravity oil from this horizon for a short while.

Structurally the Princess area lies in a saddle between the north plunging Sweetgrass Arch and the regionally, southwest dipping beds which occur to the north. The surface beds still have a very slight north plunge whereas the Palaeozoic rocks have a slight south plunge. A west component of dip is present at all horizons. The area is relatively flat and local structures stand up above the regional. The hydrocarbon pools are due to closed local structures, to lenticular pinchouts across plunging structures and to isolated zones of porosity and permeability occurring almost at random. Despite the numerous shows of oil, development work for commercial oil production has been disappointing to date.



TABER AREA

STRUCTURE CONTOURS ON TOP OF THE TABER SAND

SCALE IN MILES

B-7558-1

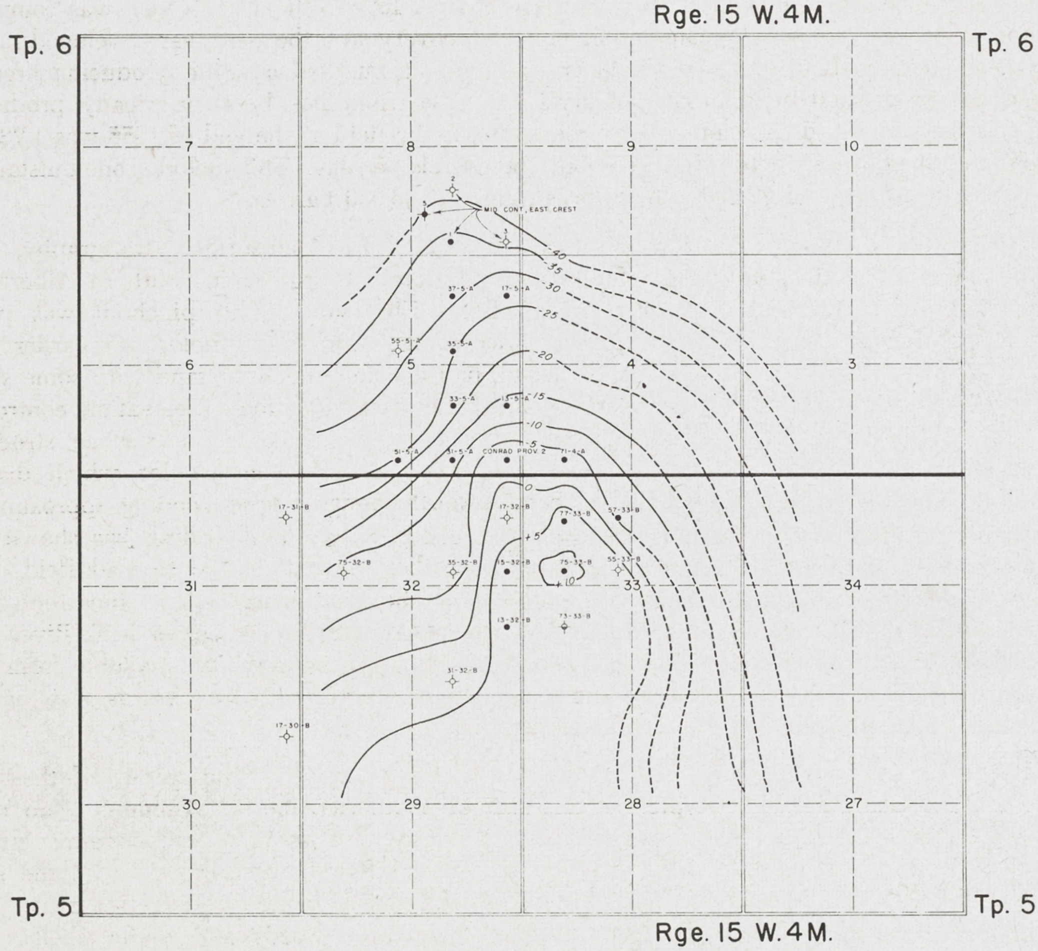
TABER OIL FIELD

The Taber oil field is located in the southern part of Alberta about 30 miles east of the city of Lethbridge. It includes an area in which many shows of oil have been found in the Lower Cretaceous Blairmore formation. It has had four areas which have actually produced oil and two areas which are still producing. The discovery well for the area was Plains Petroleum Corporation No. 2 well in Lsd. 11, Sec. 25, Twp. 9, Rge. 17, W.4th M. which was completed and brought on production in October, 1937. This well proved to have a very short production life and was a noncommercial discovery. In June, 1942 Standard Oil Company of B.C. completed its Taber Province No. 1 well in Lsd. 9, Sec. 18, Twp. 9, Rge. 16, W.4th M. as the discovery well of the East Taber Pool. Production was obtained from a Basal Cretaceous sand since termed locally as the Taber sand; the initial production rate was 250 barrels per day of 18° API gravity crude. Subsequent drilling outlined an area of about 320 acres containing 7 producers. Production to the end of 1956 was 1,054,000 barrels. The field is presently producing about 280 barrels per day. The Taber sand in this area is lentciular, grading from no sand on the northwest and south side of the field into tight silty, poorly sorted sand on the east side of the field. Where developed the sand has an average permeability of 2,860 milladarcies, and an average effective porosity of 21%. The lenticular upper surface of the sand, its excellent sorting, and the lithology of the enclosing shales suggest that it was a beach sand on the side of a Lower Cretaceous fresh water lake.

In June, 1944 Major Taber No. 1 encountered gas and oil from a Basal Cretaceous sand on the southwest part of the Taber field area. This well produced 24° API gravity oil for a short while. Subsequent drilling and production indicated that this area was only semi-commercial. In August, 1944 Standard Oil of B.C. Nassau Exploration Taber Province 87-15-A in Lsd. 13, Sec. 15, Twp. 9, Rge. 17, W.4th M. encountered 22° API gravity oil in a Basal Cretaceous sand and was placed on production as the discovery well of the West Taber field. This pool covers an area of about 600 acres and 15 wells have encountered production. Total production to the end of 1956 was 924,000 barrels and the field is presently producing at the rate of about 100 barrels per day. The reservoir at this pool consists of a lens of porous sand, developed on top of a much wider spread water bearing Basal Cretaceous sand. This upper lens develops up to 25' of productive pay, and averages about 325 millidarcies permeability and 17.3% porosity. The West Taber sand passes laterally into silts and grey shales, and does not have the lens-like shape of the East Taber sand. Lithologically both sands are some what similar having a basal conglomerate zone composed mostly of black, polished chert pebbles and grading upwards into medium-grained, salt and pepper sand with white clay cement.

Jurassic shales underlie both the East and West Taber pools and the Basal Cretaceous sands have been laid on the tilted unconformable surface of these Jurassic rocks. A north-south channel, at least 300' deep has been cut through these Jurassic shales into the underlying Mississippian limestone between the East and West Taber pools and trends underneath the original Plains pool. This channel has been filled with non-marine Basal Cretaceous sediments which possibly lie below the Taber sand.

While the Basal Cretaceous is the only present producing horizon, shows of hydrocarbons have been encountered in other rocks in this area. The Fish Scale sand has produced some gas just northwest of the area at Barnwell. A substantial blow of gas was obtained from the top of the Bow Island sand zone at California Standard 77-1-A. Some Lower Cretaceous sands above the Basal Cretaceous sand at the East Taber pool are saturated with oil and shows of oil were obtained from the Mississippian in one of the West Taber wells.



CONRAD FIELD

STRUCTURE CONTOURS ON TOP OF THE BASAL ELLIS SAND

SCALE IN MILES

0. 1 2

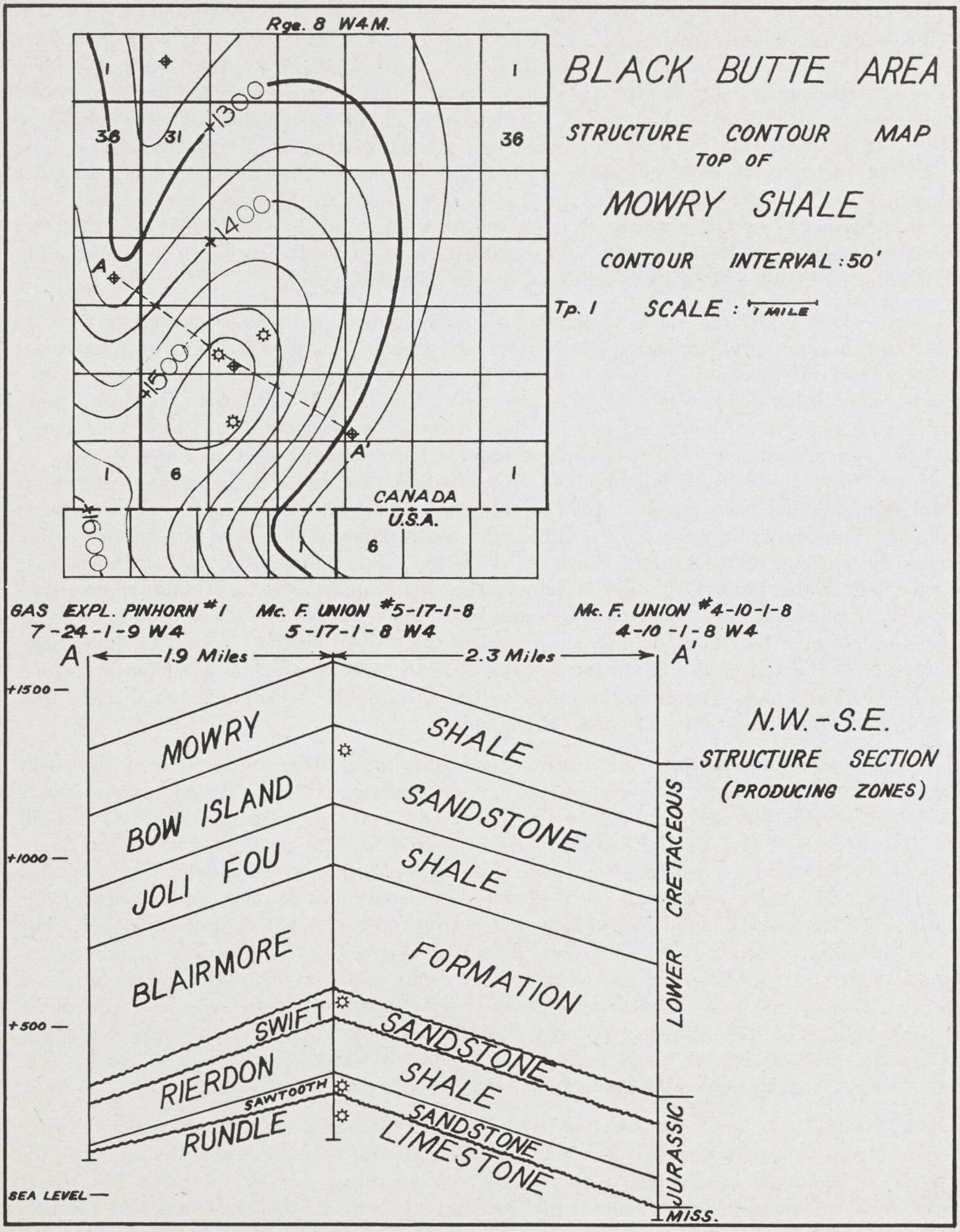
CONRAD OIL FIELD

The Conrad Oil Field is located approximately 42 miles southeast of Lethbridge, Alberta and 5 miles south of Conrad, Alberta. The field occupies parts of Sections 32 and 33, Twp. 5, Rge. 15, W.4th M. and parts of Sections 4, 5 and 8, Twp. 6, Rge. 15, W.4th M., and has a producing area of approximately 1 square mile. The discovery well for the field was California Standard Conrad Province No. 2 in Lsd. 1, Sec. 5, Twp. 6, Rge. 15, W.4th M.; this well was completed in June, 1944. Following the completion of the discovery well the field was developed rapidly and by the end of 1945 eighteen producers had been completed and the producing area has been generally defined by a number of dry holes. The field has been on steady production since this discovery and the cumulative producton for the field at the end of 1956 was 1,734,000 barrels; the present production rate is about 250 barrels per day. This includes one outstanding well, California Standard 77-33B which has produced 396,000 barrels.

The geologic basis for the location was a combination of subsurface stratigraphy, near-surface and surface structure work. Subsurface stratigraphic studies in southern Alberta indicated an up-dip pinchout of porosity in the Basal Ellis sand. This pinchout was postulated to occur generally through the present area of the Conrad oil field. An earlier well, Conrad Province No. 1, southeast of the field, had encountered tight sand with some shows and had been abandoned. The near-surface structural data consisted of elevation control on the Upper Milk River formation obtained from shallow test holes. The surface structural control was obtained from the description of outcrops along Etzikom Coulee which dissects the field. The above structural data indicated a north plunging nose trending approximately through the location of the Conrad Province No. 2 well. Subsequent drilling has shown that the pinchout of the Basal Ellis sand is somewhat farther south than the Conrad field, however a local pinchout does occur to the southeast of the field where a low limestone knob projects up through the sand. The structure which was present on the Upper Milk River horizon persists to the top of the producing horizon at least. The information available from nine wells in the field which penetrated the upper part of the Rundle formation shows that the fold is not due to drape over the Palaeozoic topography.

The producing horizon in the field is the Basal Ellis sand. The stratigraphy of the rocks above this producing horizon is typical of this part of southern Alberta. Attempts were made to ascertain whether or not hydrocarbons existed in any of these younger horizons but all tests were negative. The Basal Ellis sand in the Conrad field is considered to be the equivalent of the Sawtooth formation. It consists of an upper "Belemnite conglomerate zone", from one to three feet thick, containing chert pebbles, belemnite guards and oyster shells. The producing Conrad sand below this horizon ranges from nil to 27 feet in gross thickness. The net pay, however, averages only a few feet. Poor core recoveries and poor E-logs prevent an accurate determination of the net pay. The sand is clean, well sorted, quartzose, in part lime cemented, fine to medium-grained, occasionally having traces of glauconite ,and containing thin shale beds. The distribution of porosity and permeability appears to be very lenticular. The average permeability of samples of porous sandstone which was considered to be productive was 320 millidarcies and the average effective porosity was 17.4%.

Water was encountered over most of the field with the fringe wells commencing to cut a considerable amount of water early in their producing life; for example one of the highest wells — 73-33B — could not be completed as a satisfactory producer due to the high water cut. Considerable study has been put on this problem and it is believed that the Conrad oil accumulation has a tilted oil-water interface. The oil has thus accumulated on a slight flattening on a plunging nose generally near the up-dip pinchout of the producing horizon.


Rge. 8 W4M.
BLACK BUTTE AREA
STRUCTURE CONTOUR MAP
TOP OF
MOWRY SHALE
CONTOUR INTERVAL: 50'
Tp. 1
SCALE: 1 MILE
+1300
+1400
+1500
+1600
A
A'
CANADA
U.S.A.
GAS EXPL. PINHORN #1
7-24-1-9 W4
Mc. F. UNION #5-17-1-8
5-17-1-8 W4
Mc. F. UNION #4-10-1-8
4-10-1-8 W4
1.9 Miles
2.3 Miles
+1500
+1000
+500
SEA LEVEL
N.W.-S.E.
STRUCTURE SECTION
(PRODUCING ZONES)
MOWRY SHALE
BOW ISLAND SANDSTONE
JOLI FOU SHALE
BLAIRMORE FORMATION
SWIFT SANDSTONE
RIERDON SHALE
SAWTOOTH SANDSTONE
RUNDLE LIMESTONE
LOWER CRETACEOUS
JURASSIC
MISS.

BLACK BUTTE GAS FIELD

Location: 95 miles southeast of Lethbridge in Twp. 1, Rge. 8, W.4th M., immediately north of Alberta - Montana boundary.

Discovery: 1944, McColl-Frontenac #6-8-1-8 (Lsd. 6, Sec. 8, Twp. 1, Rge. 8, W.4th M).

(A) *Field Production:* 1956 = 1,325.8 MMCF.
Total to December 31, 1956 = 8,216.8 MMCF.

(B)

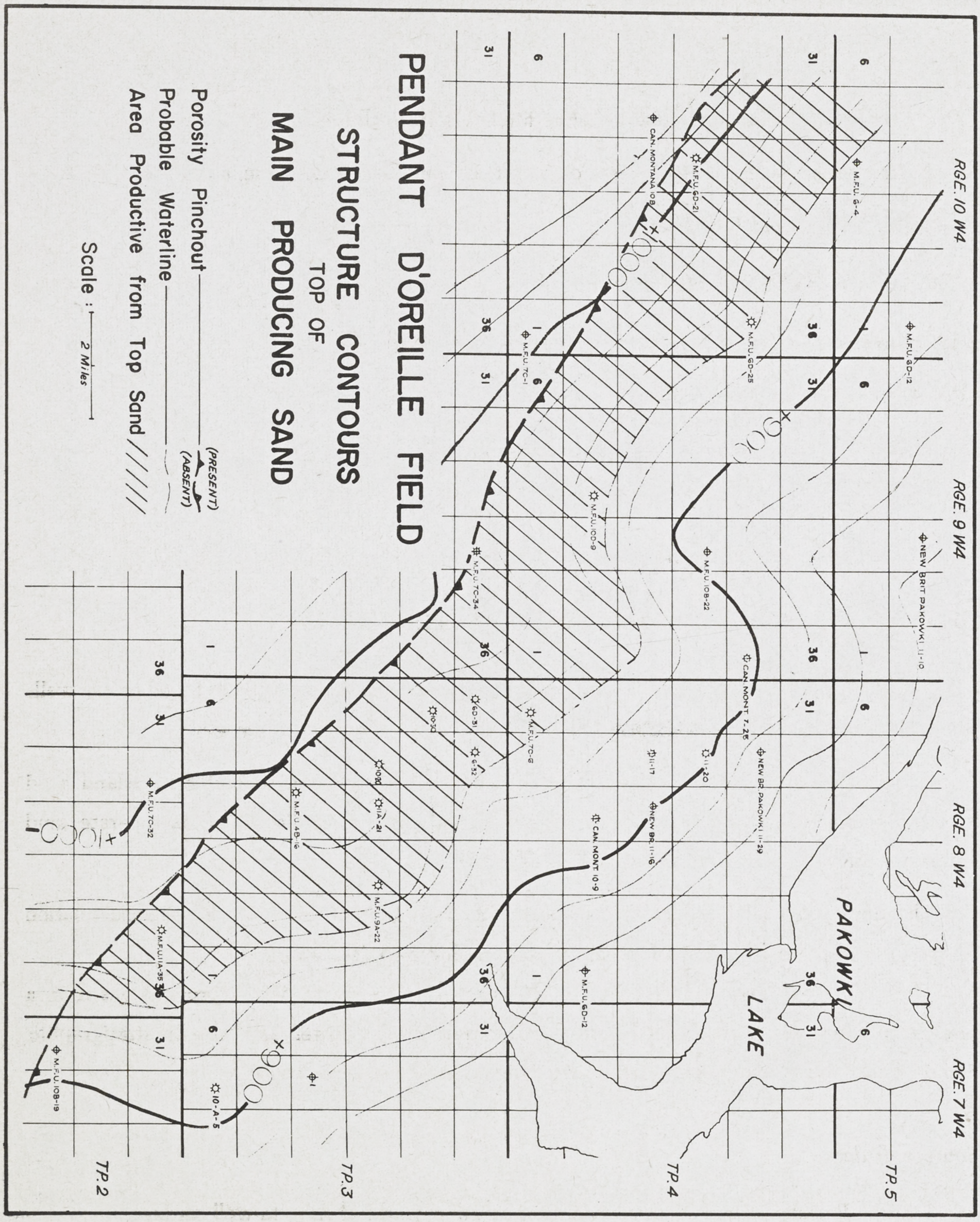
Producing Zones	–	*Age*	*Reservoir Rock Type*	*Approximate Depth*	*Average Pay*	*Disposable Gas in Billions of Cubic Feet*	*Wells Capable of Production*
Bow Island	–	Lower Cretaceous	Sandstone	2,100'	3.6'	12.0	1
Swift	–	Upper Jurassic	Sandstone	2,900'	13.3'	2.0	3
Sawtooth	–	Middle Jurassic	Sandstone	3,150'	7.1'	8.2	3
Rundle	–	Mississippian	Limestone	3,200'	16.4'	10.0	2

Trap: Structural Dome; closure probably effected by deep-seated intrusion associated with Sweetgrass Hills intrusives.

Sources of data

(A) Petroleum and Natural Gas Conservation Board of Alberta well cards.

(B) Reservoir Engineering Digest, Vol. 2 (Gas Fields), edited by S. Brodylo, Calgary. Permission for release obtained from Mr. Brodylo.


PENDANT D'OREILLE FIELD
STRUCTURE CONTOURS
TOP OF
MAIN PRODUCING SAND
Porosity Pinchout
(PRESENT)
(ABSENT)
Probable Waterline
Area Productive from Top Sand
Scale :
2 Miles
RGE. 10 W4
RGE. 9 W4
RGE. 8 W4
RGE. 7 W4
TP. 2
TP. 3
TP. 4
TP. 5
PAKOWKI
LAKE

PENDANT D'OREILLE GAS FIELD

Location: 50 miles south-southwest of Medicine Hat, Alberta.

Discovery: Made in 1946 by McColl-Frontenac and Union Oil Companies.

Producing Zone: Bow Island *Rock Type:* Sandstone.

Average Depth of Production: 2,100 feet.

(B) *Average Net Pay:* 9.3 feet. (B) *Average Porosity:* 24%.

Type of Trap: Stratigraphic.

No. of Wells Producing: 13 (from uppermost sand).
5 (from lower sands).

(A) *Cumulative Production to End of 1956:* 38.1 billion cubic feet*.

(B) *Estimated Ultimate Gross Production:* 175.0 billion cubic feet*.

* *Note:* Cumulative production and ultimate gross production figures are based on the wells producing from the uppermost sand lens only.

Gas production from the Pendant d'Oreille field is obtained from several Bow Island sand lenses, the uppermost sand being the main producing zone. A maximum of six separate sand lenses are known in the field area.

The uppermost sand ranges in thickness from an edge to 50 feet and the gas accumulation is due to up-dip sand pinchout forming a stratigraphic trap (see map).

The gas wells in Twp. 4, Rge. 8, W.4th M., except for the one in Sec. 6, produce gas from a sand lens below the main producing sand. The trap in this lower lens also is stratigraphic. Some of the other sand lenses in the area have yielded good gas shows.

Sources of data

(A) Petroleum and Natural Gas Conservation Board of Alberta well cards.

(B) Reservoir Engineering Digest, Vol. 2 (Gas Fields), edited by S. Brodylo, Calgary. Permission for release obtained from Mr. Brodylo.

DEL BONITA AREA—SOUTHERN ALBERTA

J. T. HUMPHREYS*

Summary

The Del Bonita area centres around the town of Del Bonita and usually includes the Twin River and Spring Coulee wells (see map). The area is open prairie cut by the north branch of Milk River and by a few coulees. The surface elevation varies from about 4,000 feet to 4,500 feet.

The first well was drilled in 1931 by Parco near the town of Twin River following structure test drilling. It encountered several non-commercial gas and oil shows. A year later one of the earliest seismic surveys in Alberta was used to locate a well drilled a few miles to the north. This well, among the first in the province to use acid, was abandoned after extensive testing. Further testing was carried out in 1929, 1942, 1945 and 1947.

Terminal No. 1 (Lsd. 15, Sec. 18, Twp. 1, Rge. 21, W.4th M.), completed in 1936, was the first well drilled on the Del Bonita structure. The well flowed gas from the Mississippian until suspended in 1945. There are now 12 wells within the field limits and the cumulative production is approximately 220,000 barrels of oil and 475,000 Mcf of gas. The oil has an asphaltic base and a gravity of 34° to 37° A.P.I.

Seven dry holes were drilled in the Spring Coulee area from 1924 until the discovery well in 1950. The cumulative production from four wells within the field limits was 32,482 barrels of oil to the end of 1954. The production is obtained from the upper part of the Mississippian at 5,300 feet.

Mississippian Stratigraphy

The Mississippian lithologic units have been tentatively correlated with the Turner Valley section. These units are, in descending order Middle Hard, Lower Porous, Black Lime (Shunda), Pekisko, Banff and Exshaw. At Del Bonita pre-Cretaceous erosion has removed the Upper Dense, Upper Porous and part of the Middle Hard. The partly eroded Middle Hard is 40 to 50 feet thick and is composed of light grey to light brown fine crystalline dolomite with a slight silt content and disseminated pyrite. There are irregular stringers of fine porosity commonly related to *Fenestella* zones.

The Lower Porous is about 150 feet thick at Del Bonita and 180 feet thick at Spring Coulee. It is light grey to light brown, sucrose to coarse crystalline dolomite. Porosity is present throughout, varying with the crystallinity. Most of the production is obtained from this unit with, perhaps, some from the porous stringers of the of the overlying Middle Hard.

The lithology of the Black Lime is variable. A Del Bonita it is a light grey and cream coarse crystalline dolomite with varying amounts of fragmental limestone and fine crystalline limestone. The top is marked by a well developed silt horizon and there is a varying amount of silt throughout. The unit becomes somewhat argillaceous and cherty towards the base. Porosity is poorly developed and confined to dolomite at the top and fragmental limestone at the base. The Black Lime is about 200 feet thick.

The lithology of the Pekisko member is variable and correlations are based on silty zones. The unit is composed chiefly of pale brown fine crystalline limestone with a fragmental limestone at the top. The most noticeable variation is the chert and dolomite content. In places a slight porosity is associated with the fragmental limestone. The member is 350 feet thick.

Facies changes in the Banff formation are fairly rapid in this area. Simply, the Banff is

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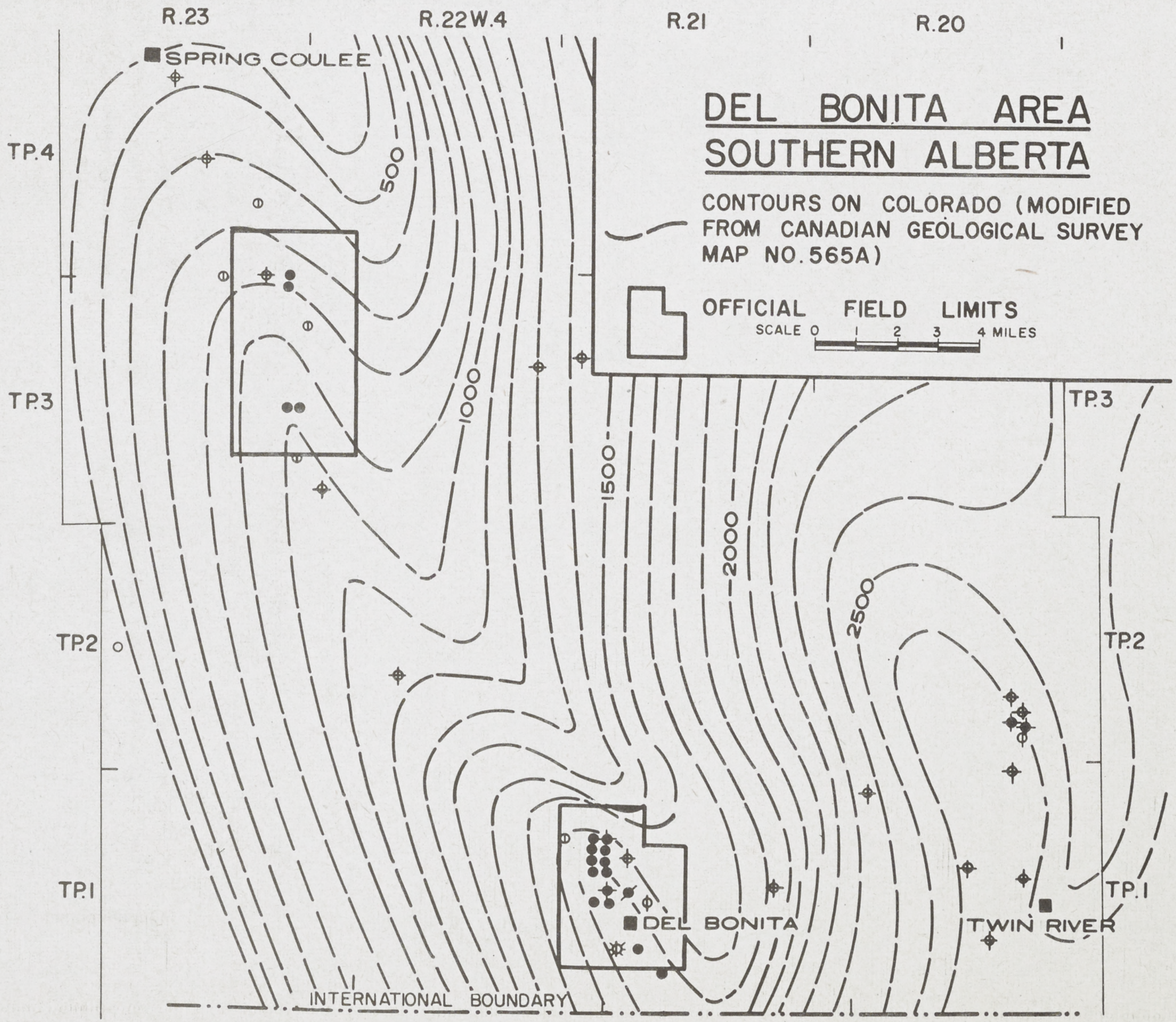

R.23
R.22 W.4
R.21
R.20
SPRING COULEE
TP.4
TP.3
TP.2
TP.1
500
1000
1500
2000
2500
DEL BONITA
TWIN RIVER
INTERNATIONAL BOUNDARY
DEL BONITA AREA
SOUTHERN ALBERTA
CONTOURS ON COLORADO (MODIFIED FROM CANADIAN GEOLOGICAL SURVEY MAP NO. 565A)
OFFICIAL FIELD LIMITS
SCALE 0 1 2 3 4 MILES

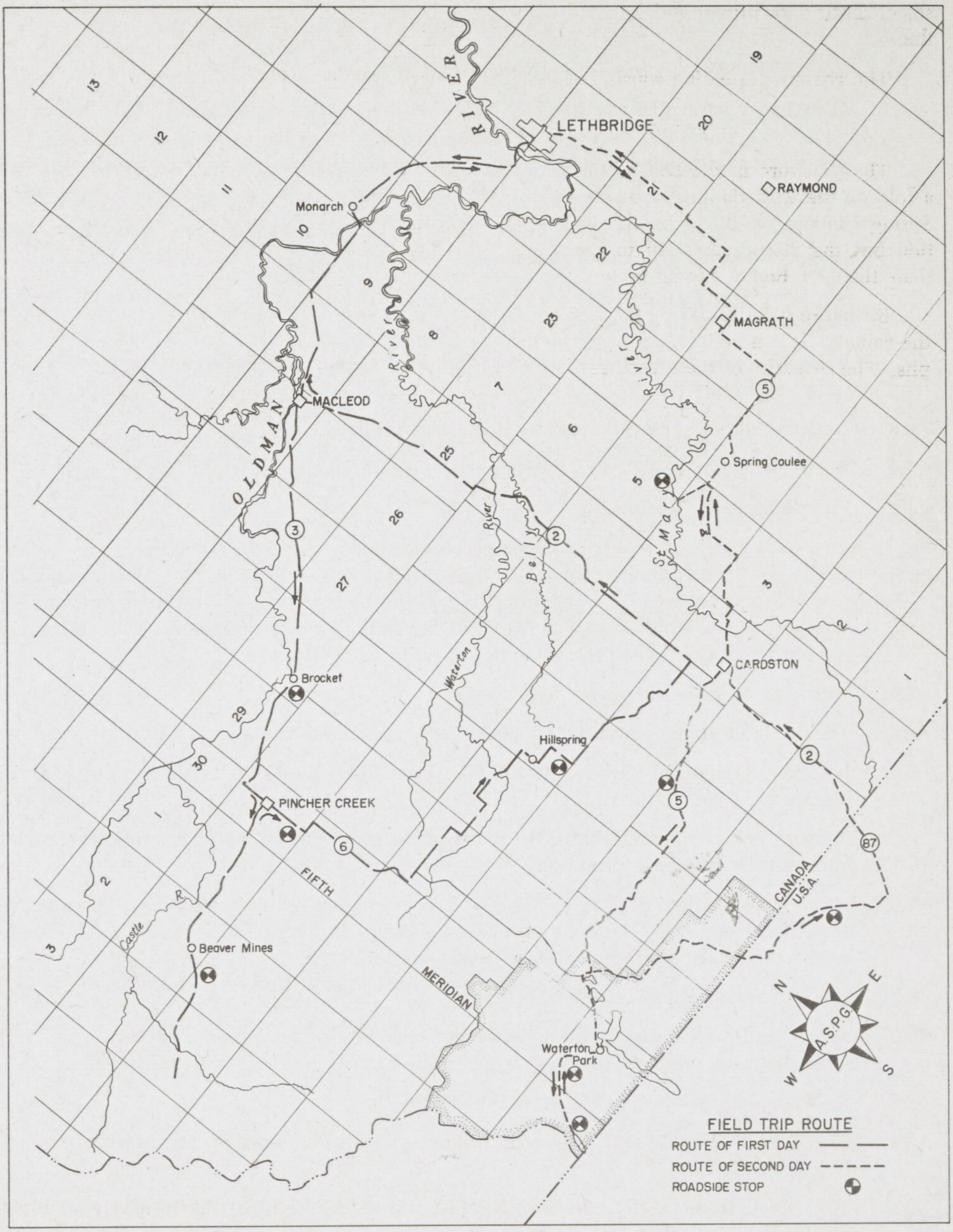
composed of dense argillaceous limestone with traces of silt, grading downward into calcareous shale. Both dark brown and light grey chert are abundant. The formation is about 300 feet thick.

The Exshaw formation consists of five feet of dark brown bituminous shale.

Structure

The structure in the Del Bonita area is shown on the accompanying map. This structure is a fold on the west flank of the Sweetgrass arch. The fold has a northwest plunge passing through Spring Coulee and dying out beyond. Local structural highs on this fold control the production but the closure is small to the south. The Twin River structure is similar to and higher than the Del Bonita structure but is not as extensive.

Structure is indicated by the few outcrops of Upper Cretaceous beds on the river banks and the coulees. It can be mapped from relatively shallow structure test wells and from air photogra phs. The structure of these beds seems to reflect the structure at depth.


LETHBRIDGE
RAYMOND
MAGRATH
Monarch
MACLEOD
Spring Coulee
CARDSTON
Brocket
Hillspring
PINCHER CREEK
Beaver Mines
Waterton Park
OLDMAN
RIVER
St Mary River
Belly River
Waterton River
Castle R.
FIFTH
MERIDIAN
CANADA
U.S.A.
A.S.P.G.
N
E
S
W
FIELD TRIP ROUTE
ROUTE OF FIRST DAY
ROUTE OF SECOND DAY
ROADSIDE STOP

First Day

ROAD LOG

ORHAN BAYKAL [1]

LETHBRIDGE – CASTLE RIVER – PINCHER CREEK

PART I. – Lethbridge to Macleod Information Bureau.

0.0 Canadian Pacific Railway Bridge. Rising 370′ from the valley floor." This bridge over which runs the C.P.R. through the Crowsnest Pass spans the valley in one mile and forty-seven feet. Completed in 1909 it is the longest and highest bridge of its type in the world.

Lethbridge Collieries #8 Mine at 10 o'clock. This mine was finally abandoned in May 10, 1957. The shaft was 265′ deep. They worked on a seam of coal 4.2 to 4.3 feet thick, found on top of Oldman formation.

The Bearpaw shale is exposed at the base of cliff. Contact of Oldman with Bearpaw formation about 1¼ miles up Oldman River.

0.8 Bearpaw shale exposed at 9 o'clock. The light seams are bentonite beds varying in thickness from 2″ to 6″.

0.9 Bearpaw shale exposed in road cut and at 9 o'clock.

1.1 Bridge over Oldman River. Bearpaw shale can be seen at 2, 4, and 10 o'clock.

1.6 Fort Whoop-up. .Plaque.

In 1869 a party of Montana adventurers unloaded a bull train a few miles south of here at the confluence of the Oldman and St. Mary Rivers and built Fort Whoop-up. They were burned out in 1871 but built a bigger and better Fort the same year to trade blankets, guns, and whiskey to the Blackfeet for buffalo robes and such. They hit out for the border in 1874 when the Mounties came to the West.

2.0 Exposure of Bearpaw shale.

2.3 The red and orange clays at 9 o'clock are burned mine dumps.

3.0 Junction of Highway No. 3 and No. 25. Turn left (West) to Highway No. 3 toward Macleod.

3.3 Railway Bridge. From Lethbridge to about Monarch for about 17 miles, the area is underlain by Bearpaw formation.

7.0 Junction to Coalhurst. Name of town is derived from old coal workings. The mine was abandoned in 1935. The coal seam occurs within the upper 85 feet of the Oldman formation and was produced from a depth of 635 feet.

8.7 Going through Kipp.

10.7 From 7 to 9 o'clock the Bearpaw shale overlain by drift is exposed at the base of the south bank of Oldman River.

15.5 Junction with Highway No. 24 to Vulcan.

16.6 Crossing projected and covered contact of Blood Reserve, St. Mary and Bearpaw formations.

The Blood Reserve thins toward N.-N.E. and at this point St. Mary may rest directly on Bearpaw shale.

17.3 Village of Monarch, crossing the Monarch fault zone.

[1] Union Oil of California.

17.5 South bank of Oldman River at 10 o'clock. The Bearpaw shale is exposed at the eastern extremity of cliff. The sandstone ridge, west of the shale outcrop is the light grey and brown sandstone of the Blood Reserve formation about 40 feet thick.

St. Mary River formation occupies the western part of bank. The beds are disturbed having been involved in the Monarch Fault.

18.5 Oldman River Bridge.

21.5 Oldman River is at 2 o'clock. Greyish, medium grained sandstone and green shale of St. Mary formation dipping 4° to 8° N.W. are exposed along the river banks.

24.4 Covered contact of Willow Creek - St. Mary River formation. The change in physiographic feature is also indicative of the contact.

25.4 Passing through Pearce and following C.P.R. line to Macleod. Willow Creek formation underlies the area for the next 45 miles.

30.3 Town of Macleod directly ahead.

33.9 Junction of Highway No. 2 and No. 3. Right turn (North) toward Macleod.

34.2 Railroad crossing.

34.8 Entering town of Macleod, one of the oldest southern Alberta settlements.

35.3 Town of Macleod.

35.9 Site of the original Fort Macleod. Plaque, "In the autumn of 1874, 150 scarlet-clad Northwest Mounted Police arrived at this site after an arduous trek across the Canadian Prairies. They selected a site on Oldman River just east of the present town and there constructed the first police post in the west." It was named "Fort Macleod", in honor of its commander Col. James F. Macleod. In the pioneering years the fort was the centre of civilization in southern Alberta.

37.1 Junction of Highway No. 2 and No. 3. Following Highway No. 3 to Pincher Creek.

PART II.. – Macleod to Castle River.

0.0 Alberta Government Information Bureau.

1.0 Railroad Crossing – The Porcupine Hills are at 1 o'clock and the Porcupine Hills formation capping those hills, dips 2 to 5° to the west. We are still on East limb of the Alberta syncline.

5.4 Entering Peigan Indian Reserve.

12.4 Crow Lodge Creek Bridge. We are travelling over Willow Creek formation.

15.3 The axis of Alberta syncline can be seen in the depression between the two hills – at 2 o'clock. Porcupine Hills formation is dipping toward the synclinal axis on hills East and West of the depression.

18.6 Crossing the covered and approximate position of axis of Alberta syncline.

20.2 STOP #1 – Brocket.

Axis of Alberta syncline is at 3 o'clock. Porcupine Hills formation exposed in north bank of Oldman River and the Willow Creek formation is found at the base of bank.

21.4 Cross-bedded, brownish, medium grained sandstone of Porcupine Hills formation exposed at 9 o'clock.

22.2 Porcupine Hills formation, dipping about 2° to the East.

22.4 Red and green shale and sandstone of Willow Creek formation at 9 o'clock. The Porcupine Hills sandstone at 8 o'clock on hill across the railroad track. The formational contact is between these two exposures.

22.6 Pincher Creek Bridge. Willow Creek formation exposed at 9 o'clock and Porcupine Hills sandstone at 11 o'clock below the railroad bridge.

23.2 Livingstone Range at 1 o'clock. Highest elevation of 8,352′, centre peak.

24.8 Micro wave communication tower at 9 o'clock. Hills from 6 to 10 o'clock formed by Porcupine Hills formation.

26.2 Railway crossing; At 2 o'clock, East dipping Porcupine Hills strata.

29.2 Porcupine Hills sandstone at 2 o'clock. The Ridge at 10 o'clock formed of folded and faulted Belly River-Bearpaw and St. Mary River formations, marks the east limit of foothills tectonics.

30.7 Highway Junction No. 3 and No. 6. Pincher Creek station to the right. Left turn (south) to Highway No. 6 toward Pincher Creek. Directly ahead is Turtle Mountain. The place where the famous rock slide occurred in 1904 can be seen as a light colored cirque shaped area. Livingstone Range is at 2 o'clock.

Behind Turtle Mountain, are Hastings and Willoughby ridges. In the background, the Main Range of Rocky Mountains overlying Lewis Overthrust and formed by faulted Mississippian and Devonian formations.

30.9 Clarke Range, at 12 and 1 o'clock, exposing Precambrian strata. Porcupine Hills formation is exposed on hills at 9 o'clock. The broad valley at 10 o'clock is underlain by Willow Creek formation.

32.4 Western Oil & Gas Consul #1, (dry and abandoned) drilled in 1907 to a depth of 1,800′, ¼ mile to the West.

32.7 Intersection. Town of Pincher Creek ahead. Left turn (East).

33.5 Pincher Creek Bridge.

34.0 Main street of Pincher Creek. Right turn (West), toward town.

35.3 Intersection. Take road to the right (North).

35.4 Bridge over Pincher Creek. Red shale and greenish grey sandstone of Willow Creek formation exposed on both sides of bridge, dipping 18 to 20° N.E.

35.5 Variegated shale outcrop of Willow Creek in road cut.

35.8 At 7 o'clock green shale and sandstone of St. Mary River formation exposed on south bank of Pincher Creek and dipping 20 to 24° N.E. The contact with Willow Creek is about 100 yards further downstream.

36.0 Approximate St. Mary River - Willow Creek contact.

36.6 Livingstone Range at 2 o'clock.

Cowley at 3 o'clock.

Turtle Mountain is at 1 o'clock with light colored area indicating the slide.

37.4 St. Mary River formation dipping about 60°, exposed along south bank of Pincher Creek at 9 o'clock.

38.3 Crossing projected trace of fault bringing Bearpaw shales in contact with St. Mary formation. Along Pincher Creek - St. Mary River formation is at 7 o'clock, and overthrust Bearpaw shale at 8 o'clock.

39.1 Projected - covered trace of fault thrusting Belly River formation over Bearpaw shales. Ridge at 7 o'clock form East flank of Castle River Anticline. The axis of the structure passes through the summit. Two wells, the Anglo-Canadian Castle River and the Alberta G & E, have been drilled in this structure to a depth of respectively 7,189′ and 3,310′.

40.3 Sandstone Ridge at 10 o'clock, formed by East dipping (60°). Belly River formation — East flank of Castle River Anticline. This Anticline is faulted on the East Flank on Belly River formation.

40.9 Crossing Axis at Castle River Anticline, trending N. 50° W. At 7 o'clock, Belly River strata, very tightly folded and probably faulted, forming Axis of the structure and dipping respectively 60° N.E. and 45° - 50° S.W. The structure is narrow and faulted .

42.0 At 8 o'clock, basal Belly River sand, underlain by Wapiabi shale thrust over Belly River formation, forming West flank of Castle River Anticline. Same Belly River sand is at 2 o'clock. From this point for about 3 miles we will have repeated Belly River formation. The ridge and valley topography, the structural alignment of hills, is also suggestive of this repetition.

42.7 Basal Belly River sand again thrust over Belly River. The faults are high angle and the strata above it dip 45° to 50° S.W.

43.1 Faulted Belly River formation over Belly River. The thrust can be traced in a S. 50° E. trend, to a ridge at 7 o'clock exposing Belly River sandstone.

43.2 Bridge.

43.8 Outcrop of Belly River, grey, medium grained sandstone, dipping 47° S.W. The strata are thrust over Belly River. The fault is east o fthe outcrop and can be traced in the same S. 50° E. trend, the wooded hills at 7 o'clock where Belly River sands are exposed at the crest.

44.4 Intersection. Road to the left going to Beauvair Lake project, (P.F.R.A.).

45.0 Crossing Mill Creek Thrust. Wapiabi formation thrust over Belly River. Trace of thrust can be seen at 1 o'clock on north bank of Mill Creek. The throw can be estimated at $\pm$5,000′. The Wapiabi, Cardium, Blackstone, Crowsnest, and Blairmore formation are sharply overturned over the thrust and form the Mill Creek Anticline.

45.1 At 11 o'clock, on northbank of Mill Creek, overturned, with a 50 - 55° S.W. dip, dark grey, silty Wapiabi shale thrust over Belly River strata.

45.7 At 9 o'clock, dark grey to black shale of Wapiabi formation forming overturned east flank of structure.

45.8 Crossing the Cardium formation which is about 40 feet thick here. Small exposure at 9 o'clock, dipping 50° S.W.

46.0 Blackstone formation on road cut, and at 9 o'clock, on Mill Creek, overturned and underlying the greenish Crowsnest volcanics.

46.1 Mill Creek Bridge. Repeated Blackstone and Crowsnest formations exposed on both sides of bridge.

46.2 Excellent exposure of Crowsnest formation on the river bank at 9 o'clock. The formation here is about 30 feet thick and consists of light grey, volcanic ash and bentonite interbedded with green shale. According to fossil plants the age is probably upper Cretaceous.

The Blackstone contact is to the left and the Blairmore contact to the right. The sharp sandstone ridges still further to the right are overturned Blairmore sands dipping about 70 - 80° S.W.

This is still the east overturned flank of the structure.

46.5 Intersection. Road to the left (South) leads to Texaco Gladstone Creek #A6-15 well about 8 miles south-southwest.

47.1 Crossing approximate position of Mill Creek anticlinal axis, trending N. 45° - 50° W. Three wells have been drilled along the trend of the axis and one well on the west flank.

The three wells are the Arrow Marjon drilled in 1945 to 5,224 feet, the Weymarn #1, drilled in 1929 to 975 feet and the Weymarn #2, drilled in 1937 to a depth of 6,430 feet. All the above three wells are about ½ mile to 1 mile S.E. from this point.

The west flank well is Alliance #1 drilled in 1942 to a depth of 6,723 feet. This well is located 1-¼ mile further west.

Travelling over Blairmore formation.

47.5 West flank of Mill Creek Anticline.

Covered trace of Crowsnest - Blairmore contact.

High Hills at 9 and 12 o'clock formed by Blairmore and Kootenay formations thrust over Wapiabi shales. The low lands at 12 o'clock underlain by Wapiabi formation.

47.8 Approximate Blackstone - Cardium Wapiabi contacts.

48.2 The Alliance #1 well, ¼ mile left (due south).

48.4 Bridge.

48.5 School House – Travelling over faulted Wapiabi formation.

50.1 Beaver Mines. Crossing fault, bringing Kootenay and Blairmore formations in contact with Wapiabi shale.

At 9 and 3 o'clock the prominent ridge is the Cadomin equivalent unconformity overlying the Kootenay formation. The Kootenay formation itself can be seen at the mine adit at 9 o'clock. The fault here underlies the Kootenay formation. The attitude of beds above the thrust varies from 30° to 40° S.W.

50.6 Blairmore exposed at 9 o'clock, dipping about 40° S.W.

50.9 Blairmore outcrop at 3 o'clock on side of hill.

Contact with Crowsnest volcanics to the West.

51.4 Travelling over covered and poorly exposed Wapiabi - Cardium - Blackstone formations.

51.5 Crossing fault thrusting Kootenay formation over Blackstone. The fault is indicated topographically too, can be traced to base of hill at 9 o'clock.

51.6 Bridge; at 3 o'clock, grey to dark grey, siliceous sandstone of Kootenay, dipping 40° S.W.

51.7 Covered and approximate position of Blairmore to Kootenay contact.

51.8 Texaco Castle River #A3-4 gas ell at 9 o'clock. Recently completed at 12,060′, as a Rundle gas well with 16,000 Mcf/d gas in restricted choke.

52.4 STOP #2.

Return to Pincher Creek.

Blairmore formation outcrops at 9 and 3 o'clock, and dips 30° to 45° S.W.
The Clarke Range at 10 and 11 - 12 o'clock. The Lewis overthrust exposed at 11 o'clock. The Precambrian strata are thrust over Upper Cretaceous Belly River formation. The dip of the thrust here varies from 25° to about 35°. Compared with the Waterton area, the Purcell series here is less folded and faulted. The oldest beds exposed are those of the Appekunny.

Gladstone Mountain at 10 o'clock. Elevation 7,777 feet – top of mountain formed by the brown-weathering Siyeh formation. Table Mountain at 11 o'clock. Elevation 7,052 feet.

PART III. – Pincher Creek to Hillspring to Macleod.

0.0 Intersection of Pincher Creek Main Street and Highway No. 6. Turn right (South).

0.5 Bridge – travelling over Willow Creek formation.

0.7 Quarter of a mile due East (left) is the dry and abandoned, Gulf-Baysel Cyr #10 well, drilled in 1956. It reached the Mississippian Rundle formation at 13,110′ (-9,325′) and bottomed in lower Rundle at 13,791 feet.

1.4 Willow Creek - St. Mary River formational contact. The soft Willow Creek forms the low land with little topographic expression and the St. Mary River forms the first set of hills marking also the beginning of foothills folding and faulting.

1.6 Bridge – At 2 o'clock in the small valley on the right, green shale and sandstone of St. Mary River formation dipping 25° N.E.

1.8 Road cut - green shale of St. Mary River with ironstone concretions.

2.2 St. Mary River formation in road cut.

3.0 Approximate St. Mary River - Bearpaw contact.

3.5 The Bearpaw shale underlies the low area, of little topographic expression. Travelling over faulted Bearpaw formation.

3.9 The topographic high is the expression of Belly River formation being thrust over Bearpaw. Crossing Hillspring Thrust.

4.5 For about 5 miles we will be travelling over faulted Belly River sections.

5.0 Crossing covered and projected trace of Okey Ridge Thrust.

6.3 Lutheran Cemetery.

6.9 Rolling Hills topography formed by repeated west-dipping Belly River formation. The ridge at 1 o'clock is the Alberta Ridge formed by Blairmore formation and faulted Colorado formation thrust over Belly River.

7.8 Approximate Wapiabi - Belly River normal contact.

8.0 Intersection. Highway makes a left turn.

9.5 Wpiabi thrust over Belly River. This is the Harland Lake Thrust which underlies the Alberta Ridge previously described.

9.8 Bridge.

10.3 Road on the left leads to Canadian Gulf Oil Company Rudolph #1 well, about ¼ of a mile S.E. The well was drilled at the N.W. extremity of Pincher Creek field in 1955, and abandoned in the Mississippian Rundle formation at a depth of 12,834 feet.

10.4 Cardium formation exposed in road cut at 3 o'clock. The formation is composed of two grey quartzitic, fine grained sand zones separated by a thick, silty shale interval.

10.5 Cardium - Wapiabi contact at road intersection. Travelling over faulted Wapiabi formation.

10.9 Wapiabi - Belly River contact. Hill at 3 o'clock formed by Basal Belly River sandstone.

11.3 Fault repeating section of Wapiabi and Belly River formations – Wapiabi is thrust on Belly River.

11.5 This section involves faulted basal Belly River sand and Wapiabi thrust on Belly River. Hills at 9 and 3 o'clock formed by Basal Belly River sand.

12.4 Approximate Wapiabi - Belly River contact.

12.8 Intersection of Highway No. 6 road leading to Pincher Creek gas field. Left turn (East) toward the gas field.

We will be travelling now over same type of section as previously described, of repeated Basal Belly River sand and Wapiabi formation.

13.6 Entering Pincher Creek Gas Field. Canadian Gulf Oil started working in the S.W. Alberta foothills in 1942. Following gravity and seismic prospecting, the first well was spudded on January 1947, a few weeks before the Leduc discovery by Imperial Oil. Pincher Creek #1 well started drilling on April 22nd, 1947, and was completed on June 19, 1948, at a depth of 12,516 feet as a Rundle gas well. The production of this well was estimated at 505 barrels of condensate and 14 MMcf. of gas per day on restricted choke. Following this discovery, several wells have since been drilled and are being drilled.

Pincher Creek Field is an over-thrusted Rundle block with an average dip of 4° to 8° S.W. The field is about 16 miles long and 1 to 2 miles wide and trends about N. 30° W. The production comes from the two porous horizons in the upper Rundle.

14.6 Gulf Walter Marr #1 on the left side completed in April 17, 1949, as a Rundle gas well at a depth of 12,768 feet.

14.9 Marr Lake at 9 o'clock. Travelling over faulted Wapiabi formation. British American Ray Marr at 11 o'clock.

15.5 Gulf W. F. Bruder #1, about ¼ of a mile south (right). Completed in 1953 at a depth of 12,415 feet as a Rundle gas well.

The road to the left leads to the new British American Ray Marr well. This well was spudded on January 2nd, 1957.

For about the next 7 miles, we will be travelling over faulted and repeated section of

Belly River formation with occasional thin slivers of Bearpaw and Wapiabi formations involved in the process of faulting. The area is fairly heavily covered by drift. The knowledge of the section is gained through exposures along river beds and physiographic features as related to different formations. The attitudes of beds varies from 20° to 40° S.W.

15.85 Harland Lakes at 3 o'clock ,area underlain by Belly River formation.

16.3 Travelling over Belly River formation. The rolling topography and structural alignment of hills (about N. 60° W.) suggest repeated Belly River formation.

17.0 British American Gas Plant at 3 o'clock. Further south at 3 o'clock, Pine Ridge.

18.5 Railroad and creek crossings.

18.8 Green Belly River shale and sand outcrop on road cut. Attitude of beds vary between 20 to 40° S.W.

18.9 STOP #3.

Excellent view of Pincher Creek field, British American Gas Plant and the Clarke Range. Waterton is at 10 o'clock and Chief Mountain klippe stands at 9 o'clock.

19.7 Road is underlain by Belly River formation.

22.0 On the horizon at 3 o'clock ,Chief Mountain appears as a truncated pyramid.

22.9 Hill across the Waterton River at 2 o'clock formed by faulted Belly River formation. Drywood Creek is aobut 1½ miles south.

24.2 Waterton River Bridge. Faulted Belly River - Bearpaw contact at left of the bridge - Okey Ridge Thrust. Belly River, greenish grey sand and green shale dipping 35° southwest exposed at 3 o'clock. The Bearpaw shale dipping 40° to 65° exposed; at 9 o'clock along the East bank of the river, normal formational Bearpaw - Belly Contact is about ¼ of a mile upstream.

24.9 Belly River exposed along Waterton River at 9 o'clock. 8he strata dip 35 - 40° S.W.

25.0 Belly River sand and shale exposed at 7 o'clock.

25.5 Approximately-projected and normal Belly River to Bearpaw contact.

26.4 Crossing Hillspring Thrust. The Belly River is faulted against St. Mary River formation. This thrust projected from the Belly River to Waterton River, will be crossed several times within the next 6 miles.

26.6 Projected and covered trace of St. Mary to Bearpaw contact.

27.1 Intersection. Right turn (South) toward Hillspring.

27.6 Irrigation Ditch. Same St. Mary - Bearpaw projected contact.

27.7 Hillspring Thrust - Hillspring ahead.

28.2 Entering Hillspring. Name of it is derived from spring water coming from side of hills behind the village.

28.7 Projected and covered Bearpaw - Belly River contact. Same contact as described on Mile 24.2.

28.8 Intersection — Left turn (East).

29.1 Railroad crossing. Bearpaw - Belly River contact again as above. The section from here to Stop #4 which is 4 miles S.E. is the same as described above.

29.9 Bridge. Crossing projected trace of Hillspring thrust.

30.1 Approximate St. Mary - Bearpaw contact.

30.6 Intersection — right turn (south). Baysel Hillspring #11-10, about 1¼ miles due East. The well was abandoned on May 24th, 1956, at a depth of 11,024 feet, after having penetrated 536 feet of Rundle.

31.1 Bearpaw - St. Mary contact again.

31.3 Covered trace of Hillspring thrust.

32.3 Intersection — Left turn (southeast).

33.2 Belly River bridge. Entering Blood Indian Reserve. This reservation is one of the largest and richest reservations in Alberta. It extends from north of Cardston to the confluence of St. Mary and Oldman Rivers to the east, northeast, and confluence of Belly and Oldman River to the west and occupies the area within those three rivers.

33.9 At 11 o'clock, along the river bank, the farthest reddish weathered exposure is the *Ostrea patina* beds of Lower St. Mary River formation. This oyster bed, found about 60 to 70 feet above the base of the formation is very widely distributed and found to the North, in Cowley map-area and to the East, in the southwestern Plains of Alberta.

At about 11 o'clock but nearer and upstream, the green shale and greenish grey sandstone of the Belly River formation are exposed. The Hillspring fault passes between those two exposures thrusting Belly River on basal St. Mary River formation. The beds are highly contorted and attitudes are from 45° to 80° S.W.

34.0 STOP #4 — about 500 yards walk to the outcrop.

At Stop #4 — The coquina oyster bed of Lower St. Mary River is exposed at 10 o'clock, dipping 27° S.W. At 12 o'clock across the valley, the sandstone ridges are faulted Blood Reserve formation. The area east and west of these exposures is underlain by the Bearpaw shale.

At the right hand side of the south bank of Belly River at 1 o'clock ,the Bearpaw shale underlies Blood Reserve formation. The Blood Reserve itself is very well exposed at 1:30 o'clock. This resistant ridge forming, grey sandstone is about 9 feet thick. The contact with St .Mary River formation is drawn at top of the sand, with the appearance of the first green or carbonaceous shales of St. Mary River. St. Mary River formation is at 2 and 5 o'clock, underiles the south bank of the river. It consists of green shale and grey to light grey medium to fine grained sandstone. The same coquinoid horizon appears as a ledge at 3 o'clock.

34.7 Re-crossing covered and projected St. Mary River - Bearpaw contact. Travelling over Bearpaw shale.

37.3 Glacial erratic, called Buffalo Stone.

38.6 At 9 o'clock on side of hill, Coquina bed of Basal St. Mary. Road underlain by Bearpaw. The Blood Reserve formation is found on top of hill at 3 o'clock across the railway track. The Bearpaw is thrust against St. Mary River formation and the fault is about 100 yards to the left.

The hills at 12 o'clock formed by faulted or folded Blood Reserve formation.

39.5 Travelling over faulted St. Mary River formation.

40.1 Hill at 9 o'clock, formed by St. Mary River and Blood Reserves formation. Top of hill capped by Blood Reserve forming a tight anticline and trend about N. 45° W.

40.9 Crossing covered trace of Blood Reserve formation, the axis of tight anticline previously described.

41.1 At 9 o'clock, about ¾ of a mile north of the road, dry and abandoned Canadian Oils Blood Reserve #6-33 well. This well was drilled January, 1957, and abandoned in the Rundle at 10,353 feet.

41.9 Tightly folded and faulted St. Mary River formation exposed along the south flank of Bullhorn Creek at 4 o'clock.

42.1 Bullhorn Coulee Bridge; travelling over St. Mary River formation.

43.4 Blood Reserve exposed at 3 o'clock across the railroad tracks – as a sharply folded and faulted anticline flanked on both sides by St. Mary River formation.

43.9 Approximate St. Mary River - Willow Creek contact. The soft Willow Creek has little topographic expression. This contact marks also the east limit of the intense Foothills folding and faulting. Eastward dips are usually 5 to 10° N.E., forming the Western Limb of the Alberta Syncline.

44.4 On the right side: St. Paul's Anglican Blood Reserve Residential School.

48.9 Intersection with Highway No. 21. Turn left (north) toward Macleod. Town of Cardston is 2 miles south.

49.2 Crossing approximate position of axis of Alberta Syncline.

53.4 2 miles due west, Blood Indian farming headquarters.

55.5 Canadian Oil Companies Blood #10-50, about 2 miles due west.

57.9 Road to Genwoodville to the west.

58.8 Irrigation Canal.

60.4 At 9 o'clock, ½ mile due west, the Western Blood #17-9 well, drilled in 1955 to a depth of 8,316′ and abandoned after having penetrated 526′ of Rundle.

63.9 At 11 o'clock Porcupine Hills. At 1 o'clock, hills formed by St. Mary River formation. The Willow Creek - St. Mary River contact is about 5 miles due east.

65.9 At 9 o'clock, monument to Head Chief Red Crow. He was born in 1830, died in 1900 and signed the Treaty in November 7, 1877.

68.1 Bridge over Belly River. We are now leaving the Blood Indian Reserve.

70.2 Waterton River Bridge. At 3 o'clock on North bank of river, S.W. dipping variegated shale and greenish-grey sandstone of the Willow Creek formation.

76.0 Royalite-Sinclair Standoff #6-21 well, about ¾ of a mile due west (left). This well was drilled in 1956 to a depth of 7,718 feet and abandoned after having penetrated 304 feet of Rundle.

81.9 At 3 o'clock, on road cut, outcrop of red and green shale and greenish and reddish sandstone of Willow Creek formation.

85.0 Sinclair-Baysel MacLeod Crown #1 well, about 3.75 miles east. Drilled in 1955 to a depth of 8,508′ and abandoned in the Devonian.

87.2 Junction of No. 2 and No. 3 highways. Turn right (east) to Highway No. 8 toward Lethbridge.

(Second Day)

ROAD LOG

LETHBRIDGE – CARDSTON – WATERTON

PART I. – LETHBRIDGE TO CARDSTON.

0.0	El Rancho Motel. Intersection with Highway No. 5. Turn right (S.E.).
0.3	Henderson Lake, at 3 o'clock. For the next 19 miles we will be travelling over Oldman formation.
1.8	Junction of Highway No. 5 and No. 4. Follo Highway No. 5.
3.1	Bridge. Only drift exposed in the valley.
4.6	Lethbridge Municipal Airport.
9.0	On the horizon at 12 o'clock is the Milk River Ridge extending in an East-West direction. The ridge is formed by Bearpaw shales, overlying the Oldman formation.
16.7	Welling Post-Office, Oldman formation exposed along Pothole Creek – 2 miles east.
17.7	Junction with Highway No. 52.
18.3	Welling Railway Station.
19.0	Crossing approximate Oldman - Bearpaw contact.
20.5	Bridge over Pothole Creek.
23.2	Town of Magrath. Travelling over Bearpaw shale.
27.0	Bridge.
27.1	Approximate Bearpaw - Blood Reserve contact. Hills at 3 o'clock formed by Blood Reserve formation.
27.5	Approximate contact of Blood Reserve and St. Mary River formation. The Blood Reserve is about 90 feet thick and the presence of *Baculites compressus* seems to indicate that the Blood Reserve formation may be older than the Fox Hills formation of Montana.
28.8	Road cut – greenish, medium grained sandstone and green shale of St. Mary River formation.
30.5	Change of physiographic feature. The rolling hill topography is due to the alternating sandstone and shale of the St. Mary River formation. The formation is about 1,500 to 1,600 feet thick and slightly folded. Dips range from 3 to 7° mostly to the S.W., and form the East limb of the Alberta Syncline.
34.6	Irrigation ditch.
35.3	Spring Coulee.
35.7	Intersection. Road to St. Mary River Dam. Turn right (east).
36.1	Bridge over Pinepound Creek.
37.1	Intersection – turn right (north).
39.3	At 12 o'clock, St. Mary River. On hills across the river, sandstone ridges formed by flat dipping St. Mary River formation. At 2 o'clock, green shale and greenish-grey sand of St. Mary River formation.
40.1	At 11 o'clock, shale outcrop of St. Mary River formation.

40.4 STOP #1 – St. Mary Dam.

At 3 o'clock exposure of St. Mary River shale just above the spillway.

At 1 o'clock excellent exposure of green sandstone and green shale of St. Mary River formation dipping about 2° 30′ N.W.

"St. Mary Project is a joint undertaking of the Government of Canada and the Government of Alberta, having as its ultimate aim the provision of sufficient water to irrigate 500,000 acres of land in Southern Alberta".

Construction of the St. Mary Dam began in 1946 and the official opening was in July

1951. "The principal features of the dam are as follows:

Height of Dam: - - - - - -	195 feet
Length of Dam: - - - - - -	2,536 feet
Base Width of Dam: - - - - -	1,480 feet
Volume of Dam: - - - - - -	4,500,000 cu. yds.
Length of Reservoir: - - - - -	17 miles
Area of Reservoir: - - - - - -	11,600 acres
Total Reservoir Capacity: - - - -	320,000 acre ft.
Spillway Capacity: - - - - -	53,000 sec. ft.

45.1 Bac kon Highway No. 5. Turn right (South).

45.7 Pothole Creek Bridge. Berry Thompson #1 well is 1 mile east. Drilled in 1948, was abandoned in the Rundle formation at a depth of 6,021 feet.

46.4 Railroad crossing.

46.7 At 8 and 9 o'clock, on the skyline, hill formed by West-dipping St. Mary River formation. Location of National Regency Mississippian oil wells.

50.4 Approximate St. Mary River - Willow Creek contact. Change in physiographic feature. The flatness of the area reflects the soft Willow Creek formation.

53.2 Railroad crossing – excellent view of the Clarke Range ahead.

54.8 Willow Creek formation exposed on road cut.

58.7 St. Mary River bridge.

59.1 At 8 o'clock, red shales of Willow Creek formation dipping 2° S.W.

59.4 Crossing approximate position of axis of Alberta Syncline.

60.9 Junction with Highway No. 2.

PART II. – Cardston to Waterton Park Gate

0.0 Junction of Highway No. 2 and No. 5 a again. Turn right on Highway No. 5 toward Waterton. Entering Town of Cardston.

0.4 Railroad crossing.

1.2 Leaving Cardston – area underlain by Willow Creek formation. Hills at 12 o'clock formed by St. Mary River formation. Eastern limit of foothills folding and faulting.

2.1 Intersection.

2.5 Approximate Willow Creek - St. Mary River contact: West limb of Alberta Syncline. The next 1½ miles underlain by faulted and folded St. Mary River formation.

3.6 Hills ahead formed by anticlinally folded Blood Reserve formation. It can be followed to the S.W., to the crest of hill seen at 8 o'clock.

4.6 Blood Reserve - St. Mary River contact.

5.0 Green shale and greenish-grey sandstone of St. Mary River formation. Hills at 8 o'clock formed by Blood Reserve thrust over St. Mary River formation.

5.7 Contact St. Mary River - Blood Reserve formations. Blood Reserve exposed at 1 and 2 o'clock.

5.8 Blood Reserve - Bearpaw contact.

6.2 Blood Reserve formation exposed in road cuts.

6.3 Blood Reserve - St. Mary River contact.

6.7 Belly River strata thrust over St. Mary River formation.

6.9 Belly River formation exposed in road cuts, dipping 30° S.W.

7.2 Belly River - Bearpaw contact. From here to Leavitt, repeated Bearpaw - Belly River formations.

Leavitt at 12 o'clock.

7.8 Creek.

8.6 At 1 0and 11 o'clock, hills formed by basal Belly River sands thrust over Belly River.

8.9 Leavitt.

9.0 Basal Belly River sand underlain by Wapiabi formation thrust over Belly River. Basal Belly River sand exposed again on hill at 11 o'clock.

10.8 Repeated sections of Belly River formation.

11.5 Basal Belly River outcrop at 9 o'clock, underlain by Wapiabi and thrust over upper Belly River.

11.7 Greyish, ridge forming, castellated outcrop of basal Belly River sand. Lenses of magnetite beds are found on top of this sandstone unit. The ridges have a striking N.W.-S.E. structural alignment.

12.3 Approximate Belly River - Bearpaw contact.

12.6 Ridge at 9 o'clock, formed by Blood Reserve formation dipping 55° S.W.

12.7 Approximate St. Mary River - Blood Reserve contact.

13.2 Basal Belly River sand and Wapiabi thrust over St. Mary River formation.

13.3 Repeated basal Belly River and Wapiabi thrusted over Belly River formation.

13.8 Repeated basal Belly River thrust against Belly River. For the next 8 miles, repeated sections of folded and faulted Belly River formation.

16.2 Basal Belly River sand again thrust over Belly River. Mountain View ahead.

17.3 Mountain View.

17.6 Clarke Range directly ahead, Chief Mountain is at 3 o'clock.

18.9 At 11 o'clock ,Birdseye Butte – at 9 o'clock Mokowan Butte. Both buttes formed by Belly River formation.

20.6 Paine Lake at 3 o'clock.

22.2 STOP #2.

Chief Mountain and Mokowan Butte at 9 o'clock. Sofa Mountain, elevation 8,268 feet, at 11 o'clock; Vimy Peak at 11:30 o'clock.

22.4 Belly River at 3 o'clock. Green shale and greyish sandstone of the Belly River formation exposed along the bank and dipping 20° N.E.

23.5 Belly River bridge. Outcrop of basal sand of Belly River formation under and left side of bridge, dipping 20 to 23° N.E. Green shale sand exposed at 3 o'clock.

23.7 In road cut to right – Belly River - Wapiabi transition zone at 9 o'clock on the south bank of Belly River. Transition zone beds are dipping 10 to 15° N.E.

23.9 Bridge of new road at 11 o'clock.

24.4 Wapiabi - Belly River formational contact.

Wapiabi outcrop on south bank of Belly River at 7 o'clock.

24.5 Road following approximate Belly River - Wapiabi contact.

Belly River formation on right side of road and Wapiabi formation on left side .

From this point to Waterton Lakes, (approximately 9 miles), the road is underlain by Wapiabi shale, and the topography is flat and expressionless.

27.0 Hill at 3 o'clock formed by the same basal sand of Belly River as seen on Belly River bridge (Mile 23.5).

27.0 Wapiabi formation on the left (S.W.) side thrust on to Belly River formation.

29.1 Vimy Peak and Waterton Townsite at 11 o'clock, Mount Crandell at 12 o'clock. Bellevue Hill and Mount Galwey at 1 o'clock.

Lakeview Ridge at 2 o'clock. On Lakeview Ridge, the Lewis overthrust with a dip of about 20 to 25°, underlies the buff colored Precambrian Siyeh formation resting on Belly River formation.

29.3 Entering Waterton – Glacier International Peace Park. In 1932 through legislation enacted by Canada and the United States, Waterton Lakes and Glacier National Parks were proclaimed the Waterton - Glacier International Peace Park.

29.7 Crooked Creek.

31.3 Junction with Highway No. 6, which leads to Chief Mountain Customs Port and Montana.

31.5 At 9 o'clock, Maskinonge Lake.

31.7 Waterton River Bridge.

31.9 Waterton Lakes National Park Gate.

PART III. – Waterton Park Gate to Akamina Road

0.0 Waterton Park Gate – The Waterton Lakes National Park was set apart in 1895. It covers an area of 204 square miles along the eastern slope of the Rocky Mountains im-

mediately north of the International Boundary.

0.1 Sofa Mountain at 9 o'clock, Vimy Peak at 10 o'clock. Waterton townsite ahead. Mount Crandell is at 12 o'clock and Bellevue Hill at 1 o'clock.

The trace of Lewis overthrust is not readily visible. The Precambrian formations above the thrust, unlike the area further north-northwest, are highly folded and faulted.

On Bellevue Hill, the base of mountain is Appekunny formation overlain by the red colored faulted Girnnell formation. The Appekunny - Grinnell sequence is again repeated halfway toward the mountain. The Siyeh formation overlying the Grinnell forms top of mountain.

Travelling over Wapiabi shales.

1.5 Waterton Lakes at 3 o'clock. Elevation 4,187 feet.

1.8 Change in physiography from subdued to rolling hills. Approximate Wapiabi - Belly River contact.

2.1 Wapiabi formation thrust onto Belly River.

2.7 Approximate Wapiabi to Belly River contact.

3.3 Crossing approximate position of Lewis Overthrust — The Siyeh formation rests on Belly River.

3.5 Intersection — Road on the right leads to Red Rock Canyon, 9 miles, West-Northwest. Straight ahead Mount Crandell, elevation 7,812 feet. At 10 o'clock, the base of Mount Crandell, formed by Appekunny. The overlying red colored formation is the Grinnell. Mount Crandell Thrust is above Grinnell formation, repeating the Appekunny formation. This last formation forms the top of the mountain. Formation at 12 o'clock is massive Altyn Dolomite thrust over Appekunny. This fault and Crandell thrust merges at base of white to grey dolomite of Altyn at 12 o'clock .

Road cut, right — Siyeh formation.

3.6 Bridge over Blackiston Brook.

Vimy Peak at 10 o'clock.

On Vimy Peak, the projecting nose at 11 o'clock formed by Altyn formation. Following the ridge to the top, base of mountain is again light grey weathering massive Altyn thrust over Altyn. The Appekunny overlies the Altyn. At about 9 o'clock, the Appekunny is overlain by the red argillite of the Grinnell formation. Mount Crandell thrust is above Grinnell and repeats a section of Altyn. The top of mountain capped by the overlying Appekunny formation.

Appekunny exposed at 4 o'clock on river bank.

At 12 o'clock, Bertha Peak, elevation 7,205 feet.

At 11:30 o'clock, Mount Richards. At 11 o'clock, Mount Campbell, elevation 8,236 feet. Mount Olson is in the background.

3.9 Prince of Wales Hotel directly ahead.

4.1 Road to Golf Course on the right side. Travelling over Altyn formation.

4.5 Altyn Dolomite in road cut.

4.7 Approximate Altyn - Appekunny contact.

5.1 Entering resort town of Waterton.

5.3 Altyn - Appekunny normal contact. Altyn formation underlies the Prince of Wales Hotel. Appekunny outcrop in road cut.

5.6 Waterton Townsite.
Road to Prince of Wales Hotel on the left side.

5.7 Altyn formation in road cut.

5.8 Junction with Akamina road.

PART IV. – Akamina Road to Cameron Lake

0.0 Junction. Turn right (N.W.) to Cameron Lake.

Travelling over Altyn formation. Waterton formation is on the left side of road and underlies the town.

0.8 Altyn formation at 12 o'clock. A thrust can be seen above the first ridge repeating the Altyn formation.

1.0 Sharp anticlinal fold in the Altyn formation. Waterton formation forms the core of the anticline at 8 o'clock.

Bertha Peak at 9 o'clock. The mountain formed mostly by repeated Altyn. Waterton formation is at the base of mountain.

1.2 Altyn formation in road cut.

1.3 Cathew Creek at 9 o'clock. Cameronian Mountain at 11 o'clock and in the background Mount Cathew at 10 o'clock exposing sections of Appekunny at base, Grinnell and Siyeh on top. Only the Siyeh formation is visible from road. Altyn formation at 12 and 1 o'clock.

1.6 Grey dolomites of Altyn formation in road cut.

1.8 Altyn formation in road cut.

2.2 Cameronian Mountain at 9 o'clock. Waterton formation is at the base of mountain. Waterton - Albyn contact is above the banded grey limestone and dolomite unit, 100 - 200′ above the river channel. Repeated Altyn sections form most of the East flank of the mountain. The Appekunny forms top of mountain.

2.4 Massive Altyn formation in road cut. Ruby Ridge at 11 o'clock with Grinnel formation exposed on top of it.

2.7 Altyn formation in road cut.

2.9 Waterton - Altyn faulted contact.

3.0 Grey dolomite of Waterton formation. At 9 o'clock, base of cliff formed by banded algal limestone and dolomite of Waterton formation underlying the Altyn, and forming sharply faulted synclines and anticlines. A fault can be seen at base of cliff under the banded limestone.

3.2 Waterton formation in road cut.

3.7 Buff weathering, cherty grey dolomite of Waterton formation. Ruby Ridge ahead. Top is capped by Grinnell underlain by Appekunny. The pronounced limestone and dolomite

ledge toward the base is the Altyn formation.

3.8 Waterton formation in road cut.

4.1 Waterton - Altyn normal contact.

4.3 Altyn formation. Next 2 miles repeated section of Altyn formation.

4.8 Road to Crandell Lake.

Altyn dolomite exposed in road cuts and on ridge ahead.

5.6 Dolomite and green argillite of Altyn formation in road cut.

5.7 Altyn formation in road cut.

6.0 Mount Blackiston at 1 o'clock.

Ridge at 12 o'clock, red argillite of Grinnell. The section above it is the Siyeh forming Blackiston Mountain.

6.3 Altyn - Appekunny contact.

At 9 o'colck, on N.W. side of Cameronian Mountain, the contacts between Appekunny - Grinnell - Siyeh, are well exposed. The red Grinnell can be seen at the saddle underlain by the Appekunny and overlain by the Siyeh.

6.5 Lineham Brook - Oil City.

Oil seepages occur on Lineham Brook about ¼ mile upstream. The first discovery well (John Lineham) Rocky Mountain Development Co. #1 was drilled in 1902 near the seepages that were known to the Indians. The well found oil in the Precambrian and according to an affidavit by John Lineham, the well produced 8,000 gallons of oil, of which 700 gallons were sold. Since the original discovery, several shallow wells have been drilled in the vicinity, without any success.

7.2 Approximate Appekunny - Grinnell contact. At 10 o'clock, N.W. face of Cameronian Mountain formed by Siyeh formation.

7.4 Rowe Brook.

Mount Lineham at 2 o'clock. Formed mostly by Siyeh formation with Grinnell at the base of it.

Grinnell formation in road cut.

7.5 Grinnell formation in road cut.

7.7 Grinnell formation in road cut.

7.9 Approximate Grinnell - Siyeh contact.

8.5 At 9 o'clock on the skyline, highest point of Cameronian Mountain. Elevation 8,499 feet.

At 8 o'clock, a green amygdaloidal basalt bed — Purcell Lava flows — can be seen overlying the red argillite of Siyeh, south of the first and nearest ridge (east of the valley cut). Following the saddle between this peak and the highest peak, the Sheppard formation, ridge forming, 600 feet thick, brown weathering dolomite overlies the Purcell lava flows. This, in turn, is overlain by the red and green argillite of Lower Kintla.

9.1 At 9 o'clock, the first ledge formed by the Purcell Lava flows; overlain by the brown weathering Sheppard dolomite and argillite.

9.3 Approximate Siyeh - Purcell basaltic Lava flow contact.

9.4 At 2 o'clock, Mount Rowe, elevation 8,043 feet, formed mostly by Kintla formation, overlying the Sheppard. The attitude of beds in this general vicinity varies between 25 to 30° S.W.

At 10 o'clock, banded, buff weathering dolomite is Sheppard formation overlain by the red argillite of Kintla formation. At 12 o'clock Akamina ridge.

9.5 Approximate Basalt - Sheppard contact.

Sheppard formation in road cut.

10.1 Sheppard to Kintla contact.

10.3 Red argillite along road.

11.0 Cameron River, Kintla formation surrounds the lake.

STOP #3.

PART V. — Junction with No. 5 and No. 6 Highway to Chief Mountain

0.0 Junction with Highway No. 6.

1.0 Wapiabi - Belly River contact. Next 8 miles folded and faulted Belly River formation.

2.8 Green shale and greenish-grey sandstone of Belly River in road cut; dipping 17° S.E.

3.2 Basal Belly River sand dipping 10° S.E. Wapiabi formation occupies depression on the right side.

5.0 View Point — Vimy Peak at 1 o'clock, Sofa Creek at 12:00 o'clock and Sofa Mountain at 11 o'clock. Trace of Livingstone Thrust is covered but is at base of cliff. From bottom to top, the base of Sofa Mountain formed by faulted Appekunny formation.

Faulted Grinnell formation overlies the Appekunny formation. The grey weathering limestone and dolomite unit belongs to the Altyn thrust onto Grinnell formation. The top of Sofa Mountain is capped by Appekunny overlying the Altyn formation.

5.7 Sofa Mountain at 3 o'clock.

6.9 Chief Mountain at 2 o'clock.

8.5 Entering Blood Indian Timber Reserve.

9.8 Basal Belly River at 3 o'clock dipping 30° S.W. on bank of Indian Creek.

10.0 Dirt road at 9 o'clock.

10.3 Approximate Wapiabi - Belly River contact.

10.6 Belly River District — Park Warden's house.

Mokowan Butte at 12 o'clock.

10.9 Creek.

11.1 Approximate Wapiabi - Belly River contact again — same contact as Mile 10.3.

11.3 Basal Belly River sand exposed at 3 o'clock dipping 15° S.W.

11.8 Belly River bridge.

12.5 Bsal Belly River sand exposed at 9 o'clock on top of hill.

13.1 Wagon road on the right side – Basal Belly River sand.

13.4 Wapiabi in road cut – Wapiabi thrust against Belly River formation.

13.8 Wapiabi shale in road cut. From here to the border the formational contact of Wapiabi to Belly River, more or less follows the road. Belly River formation forms the highlands on the left and Wapiabi, the depression at right.

16.1 Chief Mountain Customs Port.

Canada - United States International boundary.

PART VI. – Montana Road – Compiled by A. H. Johnston.

0.0 United States Customs House – International Boundary.

0.2 Plaque – "Waterton Glacier International Peace Park; United States section". Follow-in State route No. 17.

2.3 Lee Creek Bridge.

At 9 o'clock, low hills underlain by Belly River formation.

2.5 Dark greyish-brown, chunky shales of Wapiabi in road cut.

Attitude almost horizontal – approximate Belly River - Wapiabi normal contact..

2.8 Wapiabi shale in road cut.

3.5 Wapiabi shale in road cut, dipping 2 to 3° West.

4.1 Brownish-grey Wapiabi shale in road cut.

4.8 Sign – Entering Blackfeet Indian Reservation.

5.5 Wapiabi shale in road cut, dipping about 20° West.

6.1 Greenish, cross-bedded, massive basal Belly River sand – Attitude N. 60° W., and 7° S.W. Wapiabi thrust over Belly River. Next 10 miles repeated Belly River formations.

6.6 Greenish, massive, cross-bedded sandstone of Belly River formation in road cuts, attitude N. 55° W. and 11° S.W.

7.0 Belly River Sand exposed in road cut, dipping 22° S.W.

8.0 At 10 o'clock on hill side, exposure of Belly River Sand.

At 3 o'clock the Lewis Range.

8.1 Creek crossing.

8.5 Massive Belly River sand in road cut, dipping S. 50° E.

8.9 Green shale and greenish-grey sandstone of Belly River in road cut.

10.0 Belly River green shale and greenish grey sandstone in road cuts.

10.3 Belly River sand and shale in road cut.

10.4 STOP #4.

Pediment and Chief Mountain at 3 o'clock.

Chief Mountain, a Precambrian klippe, with Altyn formation resting over lower Cretaceous formation. The Lewis overthrust in this vicinity has a dip of about 8° to the west.

11.2 Creek crossing.

13.8 Massive, cross-bedded Basal Belly River sand in road cut.

14.7 Basal Belly River Sand in road cut dipping 6 to 8° West. From 11 o'clock to 4 o'clock, the flat area underlain by Wapiabi shale.

16.0 Junction with U.S. No. 89, turn left (North) toward Carway. Babb is about 4 miles south. Next 6 miles to Carway and International Boundary is a repeated Belly River section, same as described in Part II — between Leavitt and Belly River Bridge.

22.0 United States - Canada International Boundary.

PART VII. — Carway to Cardston

0.0 Carway — travelling.

0.6 Bridge. Faulted St. Mary River formation.

1.0 At 4 o'clock, on the west side of the valley cut, St. Mary River formation underlain by the Blood Reserve and Bearpaw formations. On the east side of the valley, normal Bearpaw - Belly River contact and exposure of Belly River sand and shale.

1.5 Boundary Creek Bridge. Travelling over Belly River formation. Hills at 11 and 4 o'clock, formed by Basal Belly River sand.

2.0 Some basal sand exposed at 9 and 3 o'clock, dipping 60° S.W. and thrust on the N.E. side against Belly River formation.

2.8 At 11 o'clock, Basal Belly River sand, faulted against Belly River formation. Next 4 miles repeated Belly River section. Hills ahead underlain by faulted Belly River formation.

3.9 N.W. - S.E. trend of structurally controlled hills is extremely well illustrated. Ridge forming resistant basal Belly River sand can be followed for at least 8 to 10 miles from 9 to 11 o'clock.

British American - Carway #15-15 well, 2¼ miles due west. The well was drilled in 1957 to a depth of 10,490 feet and abandoned in the Mississippian Rundle formation.

5.6 Green shale and greenish sandstone of Belly River formation in road cut.

5.9 Belly River formation in road cut.

7.7 Blood Reserve formation exposed at 11 and 4 o'clock, dipping about 40° to the S.W. Green shale of St. Mary River formation can be seen at 4 o'clock. The basal Belly River formation is thrust over St. Mary River formation. The Bearpaw formation underlying the Blood Reserve is covered.

8.6 Overturned Blood Reserve formation. Blood Reserve - St. Mary River formational contact. Next 3 miles, folded and faulted St. Mary River formation.

Ridge at 9 o'clock formed by Blood Reserve formation dipping 60° S.W.

11.7 Aetna about 2 miles east at 3 o'clock.

Approximate St. Mary River - Willow Creek contact.

Contact is projected and drawn according to change in physiographic features. From this point to Cardston area underlain by Willow Creek formation.

13.5 Outcrop of red Willow Creek shale in road cut.

13.6 Red shale of Willow Creek exposed in road cut.

13.8 Irrigation ditch.

14.6 Intersection – turn left (north). Cardston ahead, at 9 o'clock.

16.1 St. Mary River and Bearpaw formations exposed along bank of Lee Creek.

16.4 Entering Cardston.

Plaque, "The stillness of these rolling prairies was disturbed in 1887 by the creaking wheels of heavily laden covered wagons. A group of 41 resolute Mormons from Utah under the leadership of Charles Ora Card completed a hazardous trek across the unmapped frontier to settle on the banks of Lee Creek. They lived on game and scanty food supplies through the first winter and became the founders of Cardston, the famous 'Temple City of Canada'."

16.5 The famous Mormon Temple can be seen at 11 o'clock.

16.9 Lee Creek Bridge.

17.0 Town of Cardston.

17.4 Leaving Cardston.

17.8 Junction with Highway No. 5. Turn right (N.E.) on Highway No. 5, toward Lethbridge.

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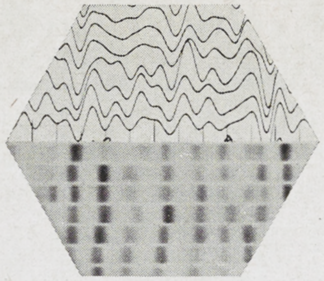
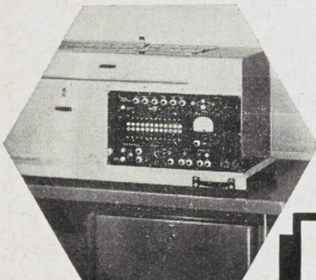
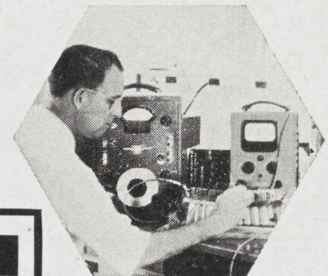


Advanced Research & Development



The Finest Equipment



Skilled Personnel

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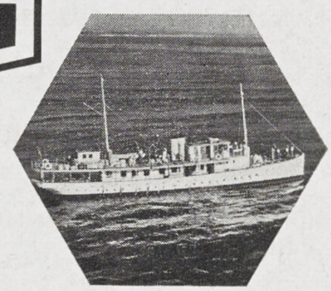
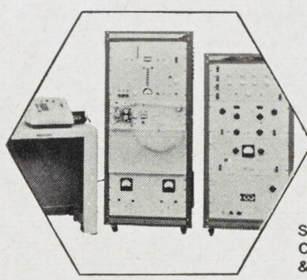
GEOPHYSICAL

Proven Dependability



World Wide Facilities



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1957
Alberta Society of Petroleum
Geologists. Field Conference
(7th: 1957)

WATERTON PARK

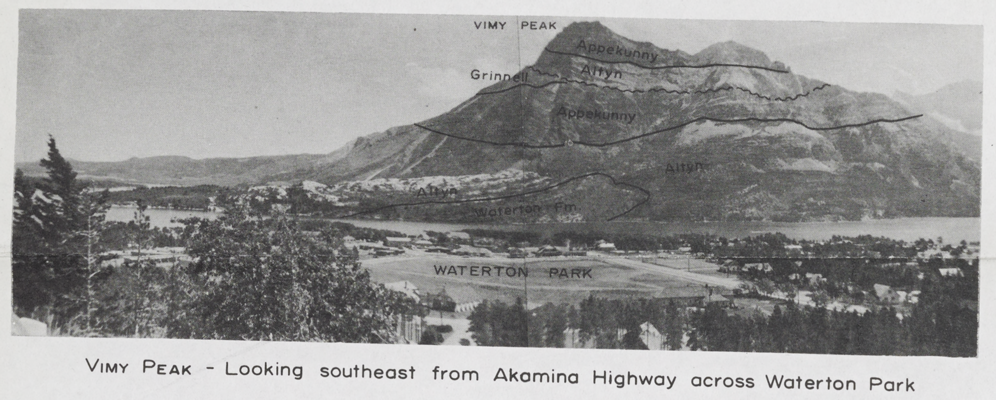
SEVENTH ANNUAL FIELD CONFERENCE

ROAD & GEOLOGIC MAP

Compilation by Orhan Baykal

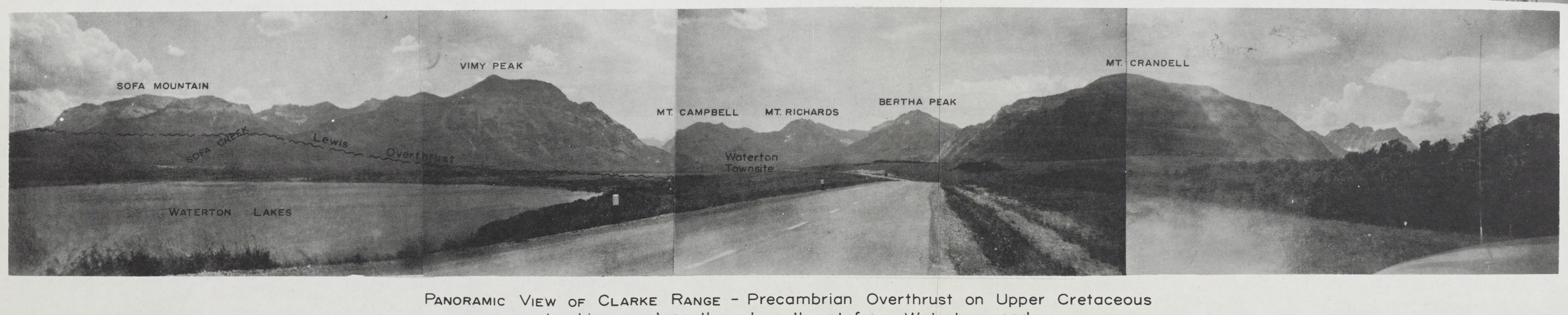
Sources of information – All published maps and reports

Drafting by Reg. Griffiths



VIMY PEAK – Looking southeast from Akamina Highway across Waterton Park

Mosaic through courtesy of GEOPHOTO SERVICES LTD.



PANORAMIC VIEW OF CLARKE RANGE – Precambrian Overthrust on Upper Cretaceous
Looking west, south and southeast from Waterton road.

LEGEND

CENOZOIC	Tph	Porcupine Hills
	Twc	Willow Creek
MESOZOIC	Ksmr	St. Mary River
	Kblr	Blood Reserve
	Kbp	Bearpaw
	Kbr-Ko	Belly River - Oldman
	Kw	Wapiabi
	Kca	Cardium
	Kbk	Blackstone
	Kcr	Crowsnest
	Kbl	Blairmore
	Kk	Kootenay
PROTEROZOIC	Ꝑk	Kintla
	Ꝑsh	Sheppard
	Ꝑbt	Basalt
	Ꝑs	Siyeh
	Ꝑg	Grinnell
	Ꝑap	Appekunny
	Ꝑal	Altyn
	Ꝑw	Waterton

Formation boundary

Fault (Triangle on upthrust side)

Anticlinal axis

Synclinal axis

Highway showing direction of route.

1st. day stops

2nd. day stops

Scale : 1" = 2 miles (approx.)

Uncontrolled Mosaic